IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

Presidential Address

THE IRON AND STEEL INSTITUTE AND THE INDUSTRY

By Richard Mather

I wish to record my gratitude to the members of the Institute for conferring on me the great honour of the Presidency. When I joined the Institute 38 years ago I was much too impressed by the stature of the previous Presidents to expect, or even hope, that I might become one of their successors. I can do little but say how deeply I appreciate the honour and that I shall do all in my power to fulfil the responsibilities of this high office.

A FEW months ago, the greater part of the iron and steel industry in Great Britain was nationalized, the units affected being brought under the ownership of the Government through the Iron and Steel Corporation of Great Britain. This concentration of so large a part of the industry is a change more far-reaching than any which the industry in Great Britain has yet experienced. It is, therefore, of interest that we should consider what effect it may have on the activities of The Iron and Steel Institute.

We may find some help in a study of the previous connection between the Institute and the industry in this country. The Institute was established in 1869 on the initiative of a group of Northern ironmasters. It was their purpose that the Institute should be the focus of discussions of current practice in the industry and of possible developments. It was not intended to be in any way a local organization, or even a purely British one. Indeed, before the Institute had been in existence for a full year the first overseas member was admitted, a Mr. Thomas Blair, ironmaster, of Pittsburgh.

Many of the first members of the Institute were actual proprietors of, or partners in, undertakings of the iron and steel industry. It is, I think, worthwhile to call attention to the initiative of these men in founding an Institute whose main objects were to break down technical secrecy and to encourage scientific study and discussion of the operations and possible developments of a great industry. We are at present passing through a phase in which many appear to think that the State is at least the main element in economic and industrial progress, and that the now unfashionable 'industrialist' was and is a man conspicuous for his many shortcomings and for the absence of qualities which are helpful to the national interest. I suggest that a perusal of the early volumes of this Institute's *Journal* will show that the industrialists of 70 or 80 years ago by no means confined their energies to developing their individual undertakings, but were active and progressive in pursuing the improvement and the technical operations of the industry as a whole.

The Institute thus began as an activity of the industry through many of its important members, who were principally owners of the works then in existence or managers of those works. I shall try to show how that connection between the Institute and the industry has developed in the intervening 80 years or so, and I shall begin by giving you my impression of the early activities of the Institute. If, in so doing, I draw your attention to some items in the early proceedings of the Institute which are not closely connected with my main theme, I trust that you will find in them some of the interest that I have experienced.

Although I shall remind you of some of the earlier

This Address was presented at the Eighty-Second Annual General Meeting of the Institute, on 30th May, 1951, with the retiring President, Mr. J. R. Menzies-Wilson, O.B.E., in the Chair.

Mr. Mather is Chairman and Managing Director of the Skinningrove Iron Co., Ltd.

features of the Institute's work and discussions, it is not part of my purpose to sketch its history. Such a history could only be undertaken by one more competent than I, and its presentation would be much more voluminous than is allowable in a Presidential Address. I will here only express a wish that in the near future such a history will be compiled for the benefit and, I think, pleasure of most of the members.

I wish to make it clear that, from the beginning, the Institute was a collection of individuals animated by a common interest, namely, the progress and development of the industry. It was not a collection of the industrial undertakings as such. The Institute has preserved this important characteristic throughout its history. I shall show you later that, when certain special circumstances have arisen, the industry, either through individual commercial undertakings or through its central organization, has provided finance for limited purposes and for limited periods. But that has never been a fundamental feature of the Institute's existence, or of its method of working. The activities of the Institute have always been and will, I hope, always remain those of the individuals constituting its membership. Membership has never been open to companies, institutions, or organizations as such. The numerous changes of ownership and consolidations of the operating units of the industry in the past have not affected the Institute's work, and it is one of the main objects of my Address to express the hope that the same will be true of the recent, and, in other respects more far-reaching, change of ownership.

The first Council of the Institute contained such names as Bolckow, Richards, Bell, Vickers, Kitson, and Nielson. Most of its members had established or greatly developed iron and steel works, which in their time occupied prominent positions in the British industry. Owing to a series of industrial amalgamations during the last half century, many of these names have disappeared from any recent list of the iron and steel works in Great Britain. The Institute has, however, been fortunate in securing the membership and the services on the Council of men of similar knowledge and experience.

The Institute was only two years old when it decided to set up a special committee to investigate the iron ore resources of Great Britain, and another committee to investigate the possibilities of developing the mechanical puddling of iron. Neither of these committees seems to have produced results of great importance, but we do see here the beginning of a direct co-operative approach to a problem (as distinct from common discussion of an individual paper on a problem) which has appeared at intervals during the life of the Institute, and which, through its most active revival about 30 years ago, ultimately led to the foundation of the British Iron and Steel Research Association. Of perhaps even more direct interest in this connection was the proposal by G. J. Snelus* in 1871 that the Institute should establish a laboratory for research : his particular objective at the time was a more rapid development of the study of the chemistry of iron and steel.

* G. J. Snelus : *Journal of The Iron and Steel Institute*, 1871, vol. I, pp. 28–46.

It was only by slow degrees, but certainly due largely to the direct and indirect influence of the Institute, that the application of chemistry and physics to the technical problems of the industry grew to its present scale. Most of the early papers were inevitably what would now be called ' practical ' papers on such subjects as the " Manufacture of Rails," " Iron as a Metal for Shipbuilding," " Modern Appliances for Reversing Rolling Mills," " Hot-Blast Firebrick Stoves," and " Danks's Revolving Puddling Furnace." All these, and others of their type, appeared within the first three years of the Institute's existence. Beside them, however, were the first of Isaac Lowthian Bell's papers on the " Chemical Phenomena of Iron Smelting " (which became the basis of his classic books on the subject), " Pyrometers," by Siemens, " The Condition of Carbon and Silicon in Iron and Steel," by Snelus, and " Spectrum Analysis," by Roscoe. It is obvious that the members of the Institute, even 80 years ago, encouraged the presentation of papers based on scientific knowledge, in the hope, which has since been fully justified, that they would in time be of great assistance to the industry.

In its early years the Institute did not confine itself closely to its own specific field. It discussed papers on shipbuilding, hydraulic valves, phosphoric bronze, rock-drills, the Yorkshire coalfield, an underground colliery fire, and a new miners' safety lamp. Perhaps the most conspicuous of these wanderings from the strict path was the paper on the proposed Channel bridge between England and France, to which (including its discussion) a hundred pages of the *Journal** were devoted. Our predecessors were obviously willing to discuss matters other than those with which they were directly concerned. Specialization was less rigid than it has become since those days.

From its beginning, the Institute attracted papers on proposed new steelmaking processes. Although few of these have survived, there is little doubt that the existence of the Institute as a focus of publication stimulated new ideas ; its discussions in several cases shortened the time during which an over-sanguine inventor continued to spend time, energy, and money on an inherently unsound project. The Institute came into being too late for the earliest discussions on the Bessemer process or on the new regenerative furnace of Siemens, but Bessemer was a member of the Provisional Committee that established the Institute, and he became its second President. Siemens was elected a member of the Institute in its first year, attended some of its earliest meetings and was elected President in 1877.

The most outstanding development which received its first public discussion through the Institute was the basic process, which Thomas and Gilchrist first announced in a paper† presented to the Institute in 1879, and followed up by a further paper‡ in 1881.

* Messrs. Schneider and Co., Creusot Ironworks, and H. Hersent : *Journal of The Iron and Steel Institute*, 1889, No. II, pp. 40–138.

† S. G. Thomas and P. C. Gilchrist : *Journal of The Iron and Steel Institute*, 1879, No. I, pp. 120–134.

‡ *Ibid.*, 1881, No. II, pp. 407–412.

If its first reception now seems to have been lukewarm, we should remember that the Institute had, in the few preceding years, discussed several other attempts at dephosphorization, all of which had been found to fail in practical trials.* The first paper by Thomas and Gilchrist, however, promptly led several manufacturers in Britain and on the Continent to try the process in their works, with such success that the names of Thomas and Gilchrist are among those most honoured in iron and steel circles throughout the world.

One feature of the early work of the Institute which has now almost entirely disappeared was its attention to the problem of making wrought iron by puddling. In the year of the Institute's formation, there were in Great Britain over 6200 puddling furnaces at work and only 59 Bessemer converters. The Institute's statistics (1870), which contain these figures, also show that 600 blast-furnaces were in blast, with an output of nearly 5½ million tons of pig iron, but no mention of any open-hearth steel furnaces is made. Presumably there were none in regular industrial operation in this country in 1869; Siemens himself said in the latter part of the year, "my process is chiefly carried on at Landore, where 75 tons of steel are now produced per week." The great predominance of wrought iron output over that of steel at that period should not be overlooked by those who study output trends from long-term statistics for steel alone. Until near the end of the 19th century, much of the use which was then, and has subsequently been, made of steel had been met by wrought iron.

From the time of the first Presidential Address there were frequent references in the proceedings of the Institute to the importance, in the words of the President at that time, of "promoting a more systematic cultivation of experimental science." It was widely realized that the growth and application of scientific knowledge would greatly stimulate the development of the industry. One of the activities of the Council was to support proposals for the erection of a building in London to house many scientific and technical societies. Expansion of technical education was advocated in a paper† to the Institute in 1876; the establishment of new centres of metallurgical training during the next decade may well have been stimulated by this paper. The year 1871 had seen the beginning of the regular publication by the Institute of abstracts of scientific and technical papers appearing in this country and overseas which were relevant to the development of the industry.

The original founders of the Institute welcomed overseas members from the beginning. As Lowthian Bell said in 1871, "every man who manufactures iron, in whatever part of the world he might be resident, would in The Iron and Steel Institute be looked upon as a friend." Within about ten years, there were 136 overseas members from nine different countries. At that time they formed an eighth of the membership, but the proportion grew to a fifth in 1900, a quarter in 1910, and to a third in 1930. Unavoidably, the proportion fell during the recent war, but the present number, 1236, is the highest on record, and constitutes a quarter of the total membership.

The exigencies of the Presidency are such that it has seldom been possible to appoint an overseas member as President. Those who did so serve, to the great benefit of the Institute, were Andrew Carnegie (U.S.A.), Adolphe Greiner (Belgium), and Eugène Schneider (France). The highest honour within the award of the Institute, the Bessemer Medal, is, however, free from the limitations of the Presidency, and of a total of 88 awards, 32 have been made to steelmakers or to metallurgists from overseas, representing ten different countries. The Institute has strengthened its contacts with its overseas members and the industries in other countries by its overseas meetings, of which the first was held in Liège in 1873. By the autumn of this year, there will have been 24 such meetings in 11 different countries. The Institute has been greatly supported by its overseas members, and by members of the industry and metallurgists in other countries, who have presented papers for discussion. The first such paper was contributed by S. Danks,* U.S.A. in 1871, and, greatly to the advantage of the Institute, the flow of valuable papers from overseas has continued almost without interruption to the present time. We are to have two excellent contributions from the U.S.A. at a later stage of the present meeting.

I have now probably taxed your patience sufficiently in my attempt to convey to you something of the impression I have received from a random glance at the records of the earliest proceedings of the Institute. The picture I have formed is that of a large and rapidly growing group of men, of much imagination and mental activity, devoting themselves to the development of their industry by exchanging, in public and critical discussion, information about methods, processes, equipment and, to an extent which was greater than has been common in later years, costs. They utilized such scientific knowledge as was available, and sought to extend it, so that they might further advance their industry. They were mainly practical manufacturers, but their wholehearted acceptance of their more scientifically learned co-members is shown by the fact that, of the first 12 Presidents, no fewer than five were, or subsequently became, Fellows of the Royal Society—a proportion which has, I think, not been reached in any subsequent period.

Such were the men who established the Institute. They laid the foundations well. The relations between the Institute and the industry were intimate and strong. The Institute received much from the industry in practical knowledge and active stimulus; it gave back at least as much in constructive criticism, systematized information, and pointers to further progress. Like the British Constitution, the connection between the Institute and the industry was never

* In his Presidential Address in 1871, Bessemer mentioned proposals to use fluorine and iodine compounds for this purpose, and reported that he had experimented by blowing "American pot ashes" through the tuyeres of a converter.

† J. Jones: *Journal of The Iron and Steel Institute*, 1876, pp. 342–346.

* S. Danks: *Journal of The Iron and Steel Institute*, 1871, vol. II, pp. 258–266.

formalized. It was unnecessary; nor would it have been possible, without serious disruption, from the time when the overseas membership grew to importance. At no time could any industrial organization or group of organizations control the policy or activities of the Institute. The Institute and the industry have benefited equally from this combination of freedom and close contact.

When the Institute was 20 years old it had become widely known and respected, and appeared to have settled down to a somewhat uneventful period. For many years there was little apparent change in the nature and scope of its activities. Its membership grew mainly among metallurgists, metallurgical chemists, plant engineers, and other technicians employed in the industry, but for a long time their influence on the nature of the papers read before the Institute was not great. The total membership reached 2000 in about 1905, and did not vary much from that figure for about 30 years. Nevertheless, the Institute played an important part in the formation of the British Standards Institution, and later in that of the International Association for Testing Materials. There was, indeed, a period during the few years before the outbreak of the 1914 war when some, at any rate, of the younger members and potential members began to wonder whether the Institute was likely to have a valuable future. By now we know that those doubts were unfounded and we can regard them merely as further evidence that even the young are not always infallible.

It was both inevitable and proper that, during the 1914–18 war, much of the activity of the Institute was devoted to dealing with the many technical problems which then arose. These problems affected almost equally the members who were mainly concerned with production, plant operation, and works development, and those whose main function was to control and improve quality and efficiency. The needs of the times led the Institute to apply a large part of its energy to the operation of research committees, which it began to set up in 1917. I have already mentioned that, in its second year, the Institute established two committees to examine particular problems, but work of this kind had been in abeyance and perhaps almost forgotten until the revival of 1917.

I need not now take up your time with any detailed account of the work of these committees, since the story was so ably and fully set out by the Institute in 1943,* when the work was on the point of being handed over to the British Iron and Steel Research Association, the formation of which had already begun to be discussed. It is sufficient here if I point out that for a period of well over 20 years this work, done primarily under the auspices of The Iron and Steel Institute, formed one of the most active links between the Institute and the industry in Great Britain. The work of these committees was fully reported in the *Journal* from time to time, and so became available to the overseas members and to other readers of the *Journal*.

The work of the research committees necessarily entailed heavy special expenditure, even though the greater part of it was done in the laboratories of individual companies in the British industry. It was manifestly impossible for an Institute with only about 2000 members to provide the necessary finance from subscriptions, and it became evident that the Institute would have to rely for an important part of its work on the provision of funds by the industry. This was arranged through the British Iron and Steel Federation (or, in the earlier years, its predecessor) which took part in the work through its Technical Department, and provided much of the special finance required by the joint committees. This co-operative action between the central organization of the industry and the Institute led to the setting up of an Iron and Steel Research Council, whose activities qualified it for a grant of part of the necessary finances from the appropriate Government department. Nevertheless, the operation of these important research committees put some strain on the finances of the Institute.

It will perhaps be convenient if I continue this part of my story by reminding you that, when the British Iron and Steel Research Association was set up, the Institute's previous work in the field of research was recognized in the constitution of the new Association by the grant to the Institute of the right of appointment of several members to the Council of the new Association. We have, therefore, a very large and active Research Association, which is financed primarily from the funds of the industry and from the Government grants which these funds attract, but of which a part of the control (through our right to appoint members of the Council) is in the hands of the Institute, which can effectively represent the individual active members of the industry. The relations between the Association and the Institute are, moreover, strengthened by the full availability of the library of the Institute to the staff of the Association, and by the arrangement under which the Institute makes part of its *Journal* available for the publication of the Association's papers. For these and other services the Association makes appropriate contributions to the funds of the Institute.

I have already indicated that, for a long period, the membership of the Institute remained practically unchanged until about 15 years ago. An upward trend then began, and it soon became evident that an expansion of the *Journal* was becoming necessary. This again faced the Institute with a financial problem, but there was every reason to expect that the publication of a journal in monthly parts instead of the previous half-yearly issues could, with the inclusion of advertisements, make the proposed large expansion of the *Journal* financially self-supporting. This scheme had been worked out by 1939, and would have been put into effect at the beginning of 1940 but for the outbreak of war.

Owing to the rise in almost all its items of expenditure from 1940 onwards, the Institute was faced with a fresh financial problem to which it could not apply the immediate relief which had been expected from the publication of a self-supporting monthly journal. It was at this stage that the Institute again had recourse to an appeal for funds from individual companies operating in the industry in Great Britain. The response was entirely voluntary on the part of the companies, and it was highly gratifying to the

* *Iron and Steel Institute*, 1943, *Special Report No.* 29.

Institute to find that so many were willing to contribute, each to the extent which it thought proper, to preserve the activities of the Institute until it could again become self-supporting. The new form of the *Journal* began to appear in 1947, and by 1950 the Institute was again able to dispense with the help of industrial contributions. Perhaps I need hardly say that the industrial contributions that were so generously given during the intervening period carried no conditions whatsoever concerning the policy and activity of the Institute.

The founders of the Institute, as I have shown, desired and encouraged the help of science in the advancement of the industry. This help was available from the beginning and was readily given. It grew steadily, and in the course of years a substantial part of the Institute's proceedings was taken up with the discussion of highly specialized papers from scientists who were already employed in the industry, or from those outside who realized that the Institute offered them a field for the contribution of additional scientific knowledge which could assist the progress of the industry. Many of the new developments, more particularly during the last 40 or 50 years, have been based largely on these contributions, and it is right that the influence of the scientific members of the Institute should have grown steadily. Almost inevitably there have been, from time to time, feelings among the members who were less highly trained that much of the Institute's work was passing beyond their grasp, and arguments have arisen about the relative importance to the Institute of 'practical' and 'scientific' papers. This gradual change was, however, inevitable, as a reflection of the growing importance of science to industry and to the country.

Most of these highly specialized, and to the ordinary members somewhat abstruse, papers dealt with problems in the purely metallurgical field. By degrees, the members of the Institute whose activities were more concerned with the engineering problems of the industry realized that they were justified in suggesting that some definite encouragement be given to the preparation and discussion of papers dealing with their type of problem. This led, a few years ago, to the formation of the Engineers Group, which has its own Committee and its own special meetings (which are, of course, open to all members of the Institute) for the discussion of papers dealing with engineering matters. This has been a valuable addition to the Institute's work, and it is not entirely surprising that even these 'practical' engineers occasionally produce papers of such a high degree of specialization that the member who is not trained in the branch of engineering particularly concerned may wonder whether he was not as comfortable in the old metallurgical frying pan as in the new engineering fire.

The outcome of all this growth has been that the Institute is now largely in the hands of practitioners in the industry who have specialized in one or more of its many branches of activity and enquiry. Those whom I may call the 'industrialist' members of the industry, whose main occupation is to keep its operating units functioning and to balance its various needs and possibilities and keep them within the bounds of what is feasible, are relatively fewer in number than they were many years ago. Nevertheless, the Institute presents both in its membership and in its many activities a well-balanced field of work for all who are interested in the fundamental well-being of the industry.

I have tried to set out the relationship between the Institute at the time of its formation and the industry at that time, and to indicate such gradual changes in that relationship as developed in the intervening years. It now remains for me to face the question indicated at the beginning of my Address.

If the consolidation into one ownership of so preponderant a part of the British industry had followed the lines of some of the other measures of nationalization, I should frankly be apprehensive of its effect on the vigour and future possibilities for good of this Institute. Throughout my Address I have tried to show that the work of the Institute has been essentially that of individuals who were free to pose their problems, state their views, and, if they thought right, to criticize the views of others, on the many matters connected with the development of the industry that came within the purview of the Institute. I believe that this freedom of discussion and criticism has been a valuable element in the progress of the industry. Neither the industry nor the Institute has, at any time, attempted to lay down any definite, official, or final pronouncement on any of the many questions which have arisen. There has always been ample scope for the expression of views by the man who does not accept what might seem to be the prevailing view at the time on any debatable subject. The organizations of the Institute and of the industry have not been such as to put any difficulties in the way of such a man. I feel that this freedom has been of great benefit.

If the recent reorganization of the British steel industry endures, it will be advisable for all of us to be more vigilant than has been necessary in the past to ensure that we remain free from any restrictions (more particularly, perhaps, indirect restrictions) of our practice of full discussion of any of the technical matters which come within the scope of the Institute. As I have said, the new form of organization of the industry is not such as immediately to cause as much apprehension on this matter as would have arisen under other forms of organization. However, administrative practices can, in the long run, be of more influence than the nominal form of an organization. These practices may, without any deliberate intention on the part of the administrators, and perhaps almost without recognition of their early effects, result in some loss of technical freedom by the individual. He may gradually find himself with fewer opportunities to express his views or to advance new ideas, whether through the medium of the Institute or otherwise.

I wish to close, therefore, on this note : the future well-being of the industry will depend, as its past successes have depended, on the freest access to open discussion, on criticism of existing practices, and on the production of new ideas and their testing in practice. The members of this Institute, in their duty to their industry, must constantly ensure that these fruitful methods of its further growth remain available to themselves and to their successors.

The Control of Electric Element Furnaces to Fine Limits at High Temperatures for Research Purposes

By T. W. Lomas, B.Sc., M. D. Jepson, M.Sc., Ph.D., and J. R. Rait, Ph.D., D.Sc.. A.R.T.C.

SYNOPSIS

One of the major problems in the measurement of creep is the accurate control of temperature, a degree of accuracy greater than $\pm 0{\cdot}10°$ C. being required if reproducible results are to be obtained. The paper discusses various types of controller, and a commercial resistance thermometer/thyratron instrument is shown to be the most suitable on the grounds of cost, availability, and performance. The range of this instrument is shown to be limited by the properties of the resistance thermometer used ; various types are described and their useful ranges are stated. The use of special types of resistance thermometer or thermistor enables the range to be extended up to 1500° C. with only slight modifications to the controller.

Introduction

RECENT advances in the design of gas turbines and developments in steam turbines have greatly increased the demand for creep-resisting steels. As a result, many alloy steel manufacturers and users have enlarged or are enlarging their facilities for the determination of creep properties. This paper contains the results of an investigation undertaken to solve the difficulty of accurate temperature control, and it is published in the hope that it will be of assistance to other firms similarly engaged.

The high-temperature properties which it is necessary to determine are :

(i) Corrosion and/or scaling resistance
(ii) Mechanical properties :
  (*a*) Short-term tests (tensile, impact, hardness, etc.)
  (*b*) Long-term tests (creep, rupture, and fatigue).

Temperature control is not of major importance in the short-term tests, and for much pass-test work limits of $\pm 2°$ C. are tolerable, and inexpensive controllers of the mechanical type are adequate. For really long-term tests, however, and for precision work of all types, much finer control is essential.

The profound influence of temperature fluctuation is illustrated by the data of Gillett and Cross,[1] from which it can be calculated that a temperature difference of 3° C. at a test temperature of 371° C. could result in a creep life of ten years being read as either 4½ or 23 years, depending on the direction of the error.

There is no doubt that even small temperature fluctuations can produce marked metallurgical changes much more rapidly than under steady conditions. An example of this is to be found in recent work[2] on the ' isothermal ' decomposition of austenite below M_s.

If the data of Gillett and Cross[1] are accepted, the reproduction of creep rates to within 10% involves control of the temperature to about $\pm 0{\cdot}10°$ C. over long periods and at temperatures up to 1000° C. For other purposes, *e.g.*, for the study of refractories, good control to better than $\pm 0{\cdot}5°$ C. was also required up to 1500° C.

The available methods of furnace control range from simple expansion types to D.C. amplifier, reactor, and similar electronic devices. The various methods can be divided into two general groups :

(i) On–off controllers
(ii) Proportional controllers.

The first type is the most common, in which the action of the thermostat is simply to switch in or out either the whole current or, better, a shunting rheostat to give high–low control. In this class are included all the expansion and most of the galvanometer types of controller, with which control to about $\pm 1°$ C. is possible.

In the simplest form of proportional control the energy input to the furnace is adjusted in proportion to the temperature out-of-balance, either with a continuously variable current or by varying the ratio of the times on high and low current. Further adjustments to give floating or even derivative control are not necessary for the control of laboratory furnaces.

Since proportional controllers are capable of giving much finer control and also, within the set limits, of maintaining more balanced conditions, it was decided to concentrate on this type of control system.

PROPORTIONAL CONTROLLERS

The two types most conveniently available are :

(1) The D.C. amplifier with saturable reactor controller.
(2) The resistance thermometer/thyratron controller.

Another type which is of exceptional sensitivity and also gives continuous control is :

(3) The resistance thermometer/reactor controller.

The D.C. amplifier controllers are based on an instrument such as the Tinsley D.C. amplifier. For use as a controller several modifications are necessary :

(i) The sensitivity must be considerably increased so that full illumination of the photo-cell represents only a few degrees Celsius and not the 1600° C. normally encountered

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Mr. Lomas and Dr. Jepson are on the staff of the Research Department of Messrs. Hadfields, Ltd., Sheffield. Dr. Rait is a Local Director of Messrs. Hadfields, Ltd.

(ii) A potentiometer must be introduced between the thermocouple and the instrument for setting the temperature at which control is to be obtained

(iii) The meter must be replaced by a reactor system to control the input to the furnace. The action of a saturable reactor is described in Appendix I.

This system is shown in Fig. 1.

Good control is obtained by this method, but there are several disadvantages resulting from the greatly increased sensitivity required and from the use of a thermocouple as the temperature-sensitive element. On the other hand, it has the following advantages :

(i) The current range in control is very wide, a ratio of 10 : 1 from maximum to minimum current being available on the reactor

(ii) The current is continuously variable from maximum to minimum, and the control is not merely high–low, nor even stepped.

Most of the disadvantages of the D.C. amplifier instrument are avoided in the resistance thermometer/reactor controller. In this instrument the sensitive element, a resistance thermometer, is part of a resistance bridge network, the output of which is fed, after amplification, into the grid of a phase-sensitive detector. This detector supplies the D.C. bias controlling the A.C. output from the reactor and hence controlling the furnace. A diagrammatic arrangement is shown in Fig. 2. The instrument is adjusted so that when the bridge is in balance the current allowed to pass by the reactor keeps the furnace at approximately the required temperature. If the temperature rises or falls, the bridge goes out of balance. As the temperature passes through the control point the phase of the amplifier output is reversed, and this, through the detector, alters the impedance of the reactor. The amplitude of the out-of-balance e.m.f. from the bridge determines the extent of the change in the current from the reactor to the furnace ; the phase of the out-of-balance e.m.f. controls the direction of the change. Again, the current is continuously variable in a 10 : 1 ratio, and is controlled directly by the amplitude of the out-of-balance on the bridge.

This system is far more elastic than that used in the D.C. amplifier controller, in that :

(i) The furnace current can be set to a predetermined value with the measuring and controlling circuits completely disconnected

(ii) The sensitivity is very high, is completely under control, and does not depend on the sensitivity of a galvanometer

(iii) Where mains interference occurs in the measuring system (*e.g.*, at high temperatures) it can be completely eliminated by feeding the bridge and detector with oscillations of a frequency different from that of the mains supply.

Although the method is most suitable for furnace control, the setting up of the instrument, involving numerous controls, requires expert attention ; although

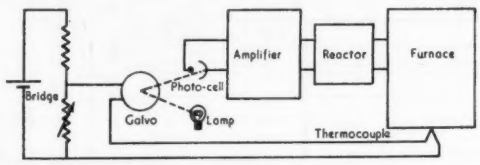

Fig. 1—Block diagram of D.C. amplifier/reactor temperature controller

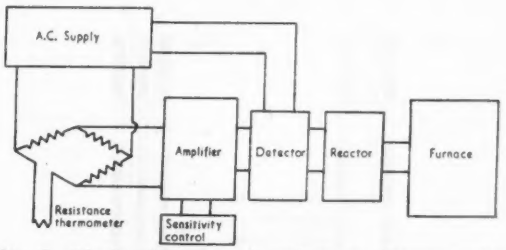

Fig. 2—Block diagram of resistance thermometer/reactor temperature controller

for specialized purposes this would be of minor importance, for large-scale use, *e.g.*, on creep testing, it is a considerable disadvantage. The expense is another important drawback. The prototype built in these laboratories contains equipment costing rather more than £100, and the total cost, taking into account the labour involved, would be far greater.

There remains the third class of proportional controller, namely, the resistance thermometer/thyratron type. Whilst there are several circuits incorporating this principle,[3] the authors' attention has been confined to the commercially available type.

The temperature-sensitive element, a resistance thermometer, again forms part of an A.C. resistance network, but in this case the out-of-balance e.m.f. is fed by way of a single-valve amplifier into the grid of a thyratron. The thyratron is set up to act as a symmetrical relaxation oscillator, fed with 50-cycle mains and firing on a 15-sec. on–off cycle. On balance the thyratron strikes every 30 sec. ; this closes a high-vacuum switch and so puts the furnace on maximum current. The thyratron remains fired for 15 sec. and then becomes non-conducting, the high-vacuum switch opens, and the furnace goes on to minimum current. On balance, therefore, the furnace is on maximum current for 15 sec. and then on minimum current for 15 sec., and so on. When the bridge goes out of balance, A.C. is fed in to the grid of the thyratron and this disturbs the symmetry of the oscillation and increases the total time period. The degree of asymmetry depends on the amplitude of the out-of-balance e.m.f., the cycling times changing from 15 : 15 at balance to, say, 25 : 10 when just out of balance to either continuously-on-maximum or continuously-on-minimum, when the temperature is a long way from the set temperature. This variation in the cycling times gives the proportionality of control. It must be noted that this proportionality is obtained by varying the time for which the furnace is set on high or low current, and not by altering a continuously variable current. For really good control a narrow current range is required, but a compromise must be made to allow for the wide variations in mains voltage that are liable to be encountered during operation.

The high–low nature of the control is satisfactory for most furnaces, but is very deleterious in a few cases where the furnace has a very rapid rate of reaction to changes in current, *e.g.*, in carbon tube furnaces. This aspect, however, is discussed more fully on p. 132.

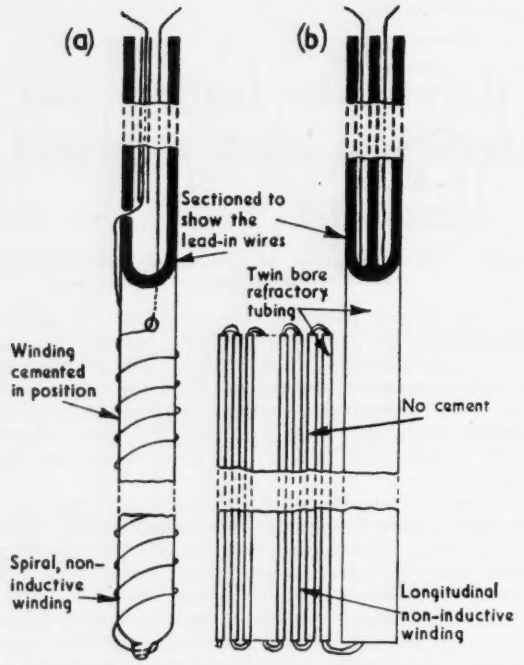

Fig. 3—Types of resistance thermometer bulb : (*a*) as originally used ; (*b*) modified form

The main advantages of this controller may be summarized as follows :

(i) It is of robust construction and self contained ; its life depends only on the life of its components, the least reliable of which are the high-vacuum switch and the thyratron, but since, up to the present, lives of over 17,000 hr. of continuous running have been recorded, this is not serious.

(ii) These units can be obtained as commercial finished products, and require no modification for use up to 800° C.

(iii) They are relatively simple to set up on furnaces, provided that suitable precautions, for example, colour coding of leads, or the use of multipoint connections, are taken.

The disadvantage of this controller, apart from the high–low system of control already mentioned, is that as a commercial product the instrument is satisfactory up to 800° C. only.

The authors required about 40 controllers to work at temperatures up to 700° C., and a few for furnace control at temperatures between 700° C. and 1500° C. It was decided to standardize on the commercial resistance thermometer/thyratron, and to attempt to modify it for use in the higher temperature range.

THE RESISTANCE THERMOMETER/THYRATRON TEMPERATURE CONTROLLER

The instrument is available in two models, to cover the nominal ranges 150–180° C. and 250–1100° C., the only difference being a slight change in the resistance values in the bridge circuits. All the present work has been carried out on the higher-range instrument, but the results are applicable to both.

The resistance thermometer bulbs originally used were made to much the same design as those supplied by the makers of the controllers. They consisted of just over three yards of 36 S.W.G. platinum wire (exactly 10 ohms at 0° C.) wound non-inductively in the form of a spiral, over a 7-in. length at one end of a ¼-in. dia. fused silica tube (Fig. 3*a*). The winding was cemented in place with a setting alumina cement of a proprietary brand.

The preliminary work was designed to determine the temperature over which control was no longer obtained, and for this purpose a Nichrome-wound resistance furnace was left under ' control ' for at least two hours at 600°, 650°, 700°, 750° C., and so on. The degree of control, observed by recording the furnace temperature on a Kent or Brown potentiometric recorder, deteriorated rapidly at temperatures above 700° C., and the equipment lost control altogether above 850° C.

It was at first thought that this failure was due to interference from the furnace winding, and the resistance bulb was accordingly surrounded by an earthed metal shield. This shielding slightly increased the useful range, but introduced thermal delays resulting in a serious loss of sensitivity which completely outweighed any advantage gained, causing the furnace temperature to cycle ± 5° C. with a period of about 10 min.

Testing Method

It was necessary to connect into the resistance thermometer circuit an indicator which would enable a measure of the extraneous effects to be obtained without at the same time disturbing the balance of the potentiometer. These conditions were fully satisfied by connecting a cathode ray oscillograph to the output of the resistance thermometer bridge

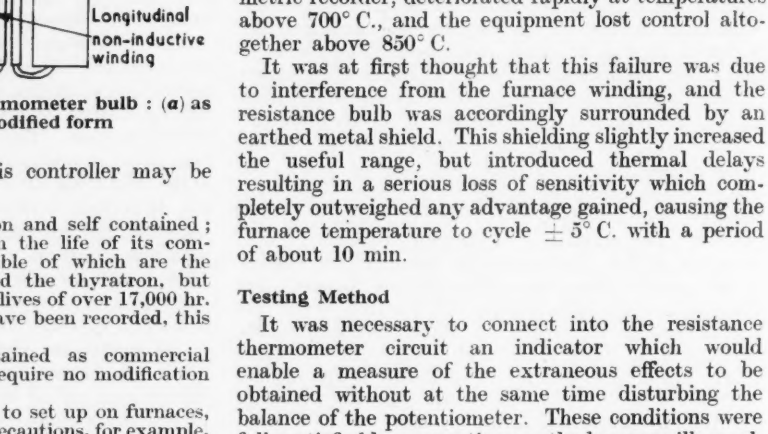

Fig. 4—Circuit diagram of resistance thermometer/thyratron temperature controller

network. For this purpose a jack-plug socket was fitted into the case of the controller and connected between point *A* and earth (*see* Fig. 4).

It was thereby possible to make a quantitative examination of the following :

(i) The A.C. potential across the bridge at balance
(ii) The wave form of the A.C. at balance
(iii) The leakage from the furnace to the resistance thermometer (by disconnecting the A.C. supply to the bridge)
(iv) Any other potentials generated in the bridge as a result of stray radiation.

If the bridge had been working perfectly all the above readings would have been zero, but in fact a certain minimum A.C. potential was always present, the lowest value recorded being about 1 mV.

Tests on Standard Type of Resistance Bulb

The first series of tests was carried out on the standard spiral-wound resistance bulb, the readings being taken at the balance points at various temperatures between 600° and 1000° C. At the higher temperatures the instrument was not controlling the furnace, and the balance was obtained manually at the particular temperature. The results are given in Table I, which shows that the factor inhibiting control is directly concerned with the balancing of the bridge network, leakage potentials from other sources being of minor importance. The only variable in the bridge network is the resistance thermometer itself, and hence the solution of the problem must lie in analysing the changes taking place in the thermometer at high temperatures.

From a consideration of the theory of A.C. bridges it is clear that, although the bridge in the controller is designed to be purely resistive, some inductive or capacitative balancing might be required. The design of the bridge and resistance bulb is such as to reduce the inductive component to a minimum ; however, it is known from other work[4] that fairly large capacitance effects can arise when refractory materials are used as dielectrics at high temperatures. It was therefore decided to investigate the effect of putting a variable condenser in parallel with the 'ballast' resistor, *i.e.*, between points *B* and *C* in the bridge network (*see* Fig. 4). It was found that

Table I

MEASURED EXTRANEOUS VOLTAGES ON A SPIRAL-WOUND RESISTANCE BULB

Instrument Setting	Temp., °C.	Voltage with A.C. at Balance, mV.	A.C. Leakage Potential, mV.	
			4-amp. Current in Furnace	Zero Current in Furnace
14·00	466	0	14	14
23·00	608	24	21	32
27·75	698	50	21	32
30·00	750	120	30	40
32·00	802	190	30	45
34·00	870	380	25	52
34·75	902	570	28	50
35·75	920	900	28	50
36·10	1003	1100	28	50

Table II

MEASURED EXTRANEOUS VOLTAGES ON A SPIRAL-WOUND RESISTANCE BULB, WITH CAPACITY CORRECTION

Instrument Setting	Temperature, °C.	Capacity, μF.	Voltage with A.C. at Balance, mV.
24·00	600	0·017	3
28·50	700	0·064	3
32·50	800	0·190	3
34·00	852	0·299	4
35·10	915	0·43	25
35·30	950	0·62	10
36·90	1010	0·93	20

after adding this condenser a transient e.m.f. was imposed on the A.C. potential at balance. This transient, having a frequency of about 10 kc./sec., was produced by feed-back from the thyratron each time it fired, when it caused a surge back into the bridge network, through the mains transformer, sufficiently large to upset the thyratron. The addition of a 0·02-μF. condenser across the secondary of the input transformer was found to reduce the transient to negligible proportions while not materially affecting the magnitude of the 50-cycle A.C. from the bridge.

Suitable adjustments of the variable condenser made a great improvement in the balance (Table II). There was also a marked improvement in the control of the furnace temperature, good control now being maintained right up to 1000° C.

Since the addition of a variable capacity of the order of 1 μF. to the bridge network would complicate the adjustment of the instrument, as well as adding to the bulk and cost of the controller and reducing to some extent the sensitivity, another solution appeared to be preferable. The information available[4] indicates that at high temperatures many refractories become semi-conductors, and the remedy would therefore appear to lie in redesigning the resistance bulbs so as to avoid the intimate contact between the wire and the cement (or refractory) and provide wider spacing of the wires.

Tests on Modified Resistance Bulbs

The type of bulb adopted, which has been used elsewhere with some success, is shown in Fig. 3*b*. The platinum wire was sheathed in fine twin-bore fused silica tubes, which were laid side by side to form a flat element, or were formed into a bundle. In both cases the fine silica tubes were fastened to a longer ¼-in. dia. silica support tube, also twin-bore, which served to carry the leads. The winding, although non-inductive, was laid longitudinally to the main support and so across the furnace winding, and was held together by wire ties. In this type of resistance bulb the wire passes down preformed tubes and does not make good contact with the refractory anywhere. As a result, satisfactory furnace control was obtained up to 1000° C. without any capacity trimming being required. The test results, which refer to an element of the flat type, with and without capacity in the circuit, are shown in Table III. Even the low A.C. balance potential obtained with this type of bulb at high temperatures can be reduced almost to zero by the addition of a small capacity, which, however, is not necessary for the successful use of the apparatus.

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Table III

MEASURED EXTRANEOUS VOLTAGES ON A LONGITUDINAL-TYPE RESISTANCE BULB

Instrument Setting	Temperature, °C.	Capacity, μF.	Voltage with A.C. at Balance, mV. No Capacity	Voltage with A.C. at Balance, mV. With Capacity
23·50	570	0·001	2	2
30·25	690	0·003	2	2
32·75	740	0·005	2	2
35·25	795	0·007	5	2
38·50	860	0·012	8	2
39·50	900	0·014	15	2
41·40	950	0·016	24	2
43·25	1002	0·020	26	2

With the new type of bulb there was an increase in the stability of the apparatus, and it has now become general practice to maintain the sensitivity setting at the maximum value of 10, in comparison with the value of 4 on the old type.

At this stage it was felt desirable to examine the behaviour of other types of refractory tube instead of the fused silica. Sillimanite and recrystallized alumina were tried, the results being given in Table IV. Comparison of these results with those given in Table III shows that there is very little significant difference up to 1000° C.

TEMPERATURE SENSITIVITY OF THE RESISTANCE THERMOMETER/THYRATRON CONTROLLER WITH THE MODIFIED RESISTANCE BULBS

When the controller is cycling and controlling the furnace, *i.e.*, is on balance, the small temperature changes of the resistance bulb are indicated by the changes in amplitude of the trace on the cathode ray oscillograph. To convert this amplitude into a measure of the temperature change the oscillograph must be calibrated by obtaining:

(i) The relationship between the temperature at balance and the potentiometer setting
(ii) The relationship between the A.C. out-of-balance potential on the oscillograph, and the potentiometer setting, a fixed resistance being used in place of the resistance thermometer.

Table IV

TEST RESULTS ON LONGITUDINAL-TYPE RESISTANCE BULB

Instrument Setting	Temperature, °C.	Capacity, μF.	Voltage with A.C. at Balance, mV.
Sillimanite Tubes			
25·75	595	0·008	3
31·00	692	0·008	...
36·00	798	0·020	...
38·00	848	0·024	...
40·00	897	0·026	...
42·10	952	0·028	...
44·10	1004	0·030	...
Recrystallized Alumina Tubes			
26·00	595	0·006	...
31·00	690	0·009	...
36·00	795	0·024	1
38·25	850	0·027	1
40·25	898	0·025	1
42·25	953	0·021	1
44·10	1002	0·023	...

The values obtained for temperatures in the region of 900° C. are given in Tables V and VI.

The relation between temperature and out-of-balance potential was obtained graphically, the value being approximately 50 mV./° C. at 900° C. Since the maximum variation of amplitude on balance was 5 mV. at 900° C., the variation in temperature *at the resistance bulb* was of the order of ± 0·05° C. on sensitivity 10. In some cases no detectable change in amplitude occurred over periods of about half an hour, and during this time the temperature changes must have been very much smaller than that given above. These periods of very good control occurred when the mains voltage was steady. When a change in mains voltage occurred, the on–off times of the controller altered slightly to compensate and for a time the more normal control range (± 0·05° C.) was maintained. As changes of more than ± 20 V. had been observed during experiments, it was necessary to know whether the controller was able to accommodate such large variations without losing control.

To investigate changes in the furnace input voltage it was necessary to determine the range of bulb resistances over which proportional control was maintained, and to relate the limits of this range to the temperatures they represented and so to the voltages which would, under steady conditions, maintain those temperatures. A standard resistance box was set to represent a temperature of approximately 900° C., and the temperature setting control on the instrument was varied. This control was graduated from 0 to 50 in divisions of 0·01, and the setting was varied one division at a time, *i.e.*, approximately 0·2° C. (*see* Table V). The cycling times were measured on a 3-pen tape chronograph, the first pen recording ½-sec. impulses from a master clock, the second recording the on–off times of the thyratron, and the third recording the action of the hot-wire vacuum switch. This method gives consistently accurate records of the cycling times to within 0·1 sec., and

Table V

TEMPERATURE CHARACTERISTIC OF THE INSTRUMENT POTENTIOMETER

Instrument Setting	Temperature, °C.
38·00	837
39·00	862
40·00	887
41·00	910
42·00	937

Table VI

VOLTAGE CHARACTERISTIC OF THE INSTRUMENT POTENTIOMETER AT 900° C.

Instrument Setting	Voltage with A.C. Out of Balance, mV.
39·65	660
39·75	510
39·85	400
39·95	280
40·05	122
40·10	70
40·15	21
40·20	42
40·25	92
40·35	240
40·45	370
40·55	500
40·65	620

has been used very successfully to check the operation of controllers requiring adjustment or repair.

The range of settings within which proportioning was maintained was found to be from 40·06 to 40·20, between which limits the total cycling times and proportional cycling times varied as shown in Fig. 5. These limits are equivalent to a total temperature range of 2·5° C., *i.e.*, a fall or rise of 1·25° C. takes the instrument from balance to either 100% on or 100% off. With the current settings in use, a current of 5 amp. will vary by ± 0·9 amp., which represents a mains change of 230 ± 40 V. With:

230 V. input ≡ 900° C. controlling 50/50

an increase in voltage to 270 V. changes the current range from approx. 4·1–5·9 amp. to approx. 5·0–6·8 amp. To accommodate this change the instrument must go out of balance sufficiently to maintain itself 100% on minimum current. This degree of unbalance on the bridge network can only be obtained, as shown above, by a temperature rise of 1·25° C. Therefore:

230 + 40 V. input ≡ 900° + 1·25° C. controlling 100/0

or

230 − 40 V. ,, ≡ 900° − 1·25° C. ,, 0/100

Over this control range, therefore, the temperature change with voltage, due to proportional control, is approximately 1° C. per 30 V., *i.e.*, a change in mains voltage of about 30 V. will cause the instrument to alter its control point by 1° C.

To obtain control to ± 0·10° C., the mains voltage must therefore be controlled to within ± 2 V., whilst if better voltage control is possible extremely fine temperature control can be obtained. On the other hand, if voltage control is not available it is of little use to employ an instrument capable of better than ± 0·10° C. when mains voltage changes of the order of 15 V. (unfortunately all too common today) can cause changes of 0·5° C. in the control level.

THE EFFECT OF VARIOUS CEMENTS ON SPIRAL-WOUND RESISTANCE BULBS

It was considered advisable to investigate the behaviour of certain types of cement, so as to confirm that the failure of the original type of spiral-wound resistance bulb was due to the properties of the refractory cement at high temperature. For this purpose, short spirals of platinum wire were wound on lengths of silica tube and were coated with various cements. After suitable baking treatments the bulbs were tested by comparing their capacity at a particular

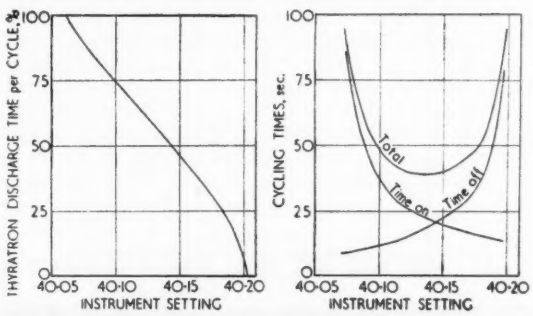

Fig. 5—Cycling time characteristics at about 900° C.

Table VII

TEMPERATURE/DIELECTRIC CHARACTERISTIC OF CERTAIN CEMENTS

Temp., °C.	Capacity, μμF.			
	Alumina and Setting Agent	Kaolin and Sodium Silicate	Silica and Silica Gel	Magnesite
0	210	150	...	120
250	271	245	224	121
400	380	1200	...	130
500	1800	4640	293	136
650	5300	...	690	250
700	40,000	94,000	1190	...
800	121,000	250,000	6500	...
850	170,000	390,000	...	510
900	270,000	700,000	32,000	1200
1000	710,000	1,600,000	65,000	9500

temperature with that of a standard bulb coated with the original cement.

If the large capacitance effects are due to the formation of some melt in the cement, as was suspected, the presence of a low-melting-point silicate, such as sodium silicate, would be deleterious. One bulb was therefore coated with a mixture of kaolin and sodium silicate, a mixture often used for cementing refractory members into metal fittings on dilatometers and similar equipment. The second cement tested employed silica gel as the setting agent for a fine siliceous powder, and the third was an experimental magnesite cement developed in these laboratories,[7] and contained no setting agent. Each test bulb was examined at various temperatures up to 1000° C.; the results are given in Table VII.

These capacity values cannot be compared directly with the results given earlier, since the forms of the resistance bulbs were different. However, the spiral-wound bulbs using the alumina cement were found to be satisfactory up to about 700° C., and at this temperature the test bulb had a capacity of 40,000 μμF. It is probable, therefore, that a thermometer of this type will work satisfactorily provided that the corresponding test-bulb capacity does not exceed 40,000 μμF. The maximum working temperatures for spiral-wound resistance bulbs coated with the cements listed will be approximately:

Alumina with setting agent (original proprietary brand of cement for use with platinum)	700° C. (from experiment)
Kaolin and sodium silicate	600° C.
Siliceous powder and silica gel	900° C.
Magnesite	>1000° C.

The magnesite-coated resistance bulb can therefore be expected to give satisfactory service at temperatures above 1000° C., and it was decided to check this by constructing a full-resistance bulb and coating it with magnesite.

SPIRAL-WOUND RESISTANCE BULB WITH MAGNESITE COATING

The design of the new bulb was the same as that of the original spiral-wound thermometer (Fig. 3*a*)

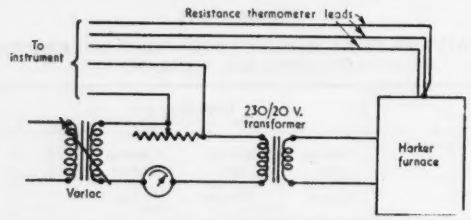

Fig. 6—Circuit used with the Harker furnace

but, as it was to be subjected to temperatures up to 1600° C., the support tube had to be either alumina or mullite, the latter proving more satisfactory. For working at temperatures up to 1500° C. it was found necessary to use a Harker carbon-tube furnace, as a platinum-wound furnace was not available. The Harker furnace consists of a carbon tube which is directly heated by the passage through it of a high current at low voltage, the tube being packed in carbon black. This furnace has been considered to be virtually uncontrollable ; the resistance of the tube is never constant, and its rate of reaction to changes in the input is extremely rapid. The latter condition made it essential to shorten the total cycling time of the controller from 30 sec. to about 12 sec., which was as low as could be conveniently obtained. Additional resistance in the bridge network had also to be provided to accommodate the higher temperatures involved. For this purpose a decade resistance box was connected in the compensating leads of the resistance bulb, breaking in at point *C* (*see* Fig. 4), and was brought into use when necessary. The furnace current was controlled by means of a Variac transformer in the primary circuit of the 230 : 20 V. step-down transformer, supplying the current to the furnace. A 2·4-ohm shunt resistance provided the high–low current when connected in or out by the controller. This circuit is shown in Fig. 6. The results of the experiment are given in Table VIII ; up to about 1280° C. they were as expected, the furnace being under control to better than ± 1° C. when the capacities had been balanced out. The capacity balancing was only required at temperatures above 1100° C. Between 1275° and 1300° C., however, control was lost, only to be regained at 1335° C., although with a major difference : the resistance of the bulb was now falling with rising temperature, and the phase of the A.C. feed to the bridge network had to be reversed, by interchanging the connections at *B* and *F* in Fig. 4. This change could be due only to the resistance of the cement becoming less than that of the platinum wire. Up to about 1275° C. the furnace was under control by means of a platinum resistance bulb ; between 1275° and 1300° C. the resistances of the platinum and of the refractory were much the same, and there was a period of instability ; above 1300° C. the control element was, in effect, a magnesite resistance bulb, acting as a thermistor.

Table VIII

INSTRUMENT AND EXTERNAL CONTROL SETTINGS AT HIGH TEMPERATURES

Magnesite-Coated Resistance Bulb

Instrument Setting	Extra Resistance, ohms	Temperature, ° C.	Capacity, μF.
26·00	0	605	...
31·00	0	693	0·002
36·00	0	790	0·008
40·00	0	894	0·020
44·50	0	992	0·022
47·50	0	1072	0·025
47·50	1·9	1190	0·030
47·50	3·1	1258	0·075
47·50*	2·5*	1335*	0·190*

* These readings were taken with the phase of the A.C. feed to the bridge network reversed.

THERMISTORS

A thermistor consists of a layer of semi-conducting material separating, and in close contact with, a pair of conducting leads. Such a system has a very high resistance at room temperatures, but it has also a very high negative temperature coefficient of resistance (approximately ten times that of metals) so that at high temperatures the resistance may be only one or two ohms. The temperature/resistance characteristic of thermistors depends mainly on the type of material used and on the dimensions. A thermistor made up for furnace control experiments consisted of a central straight platinum wire which was thinly coated with magnesite and was then wound with a spiral of platinum wire. This assembly was then coated with more magnesite to make a solid unit. A unit of this type was heated a number of times to a temperature above 1600° C., and after the first heating was found to give a fairly reproducible resistance/temperature curve (Fig. 7). At high temperatures a marked capacitance effect comes in and has to be balanced out before the resistance balance can be obtained. A spiral-wound resistance thermometer in which the resistance of the refractory is lower than that of the platinum element would therefore in fact be a thermistor if the wire were cut at the tip of the thermometer, leaving two parallel spirals separated by narrow bands of refractory. To confirm that the 'resistance' bulb, acting as a thermistor, was capable of controlling the furnace, a thermometer was cut at the tip and was tested between 1300° and 1600° C. With the phase of the A.C. supply to the bridge reversed, and with the resistance box in the compensating leads to allow for the large resistance changes, the capacities required to obtain a balance at various temperatures were :

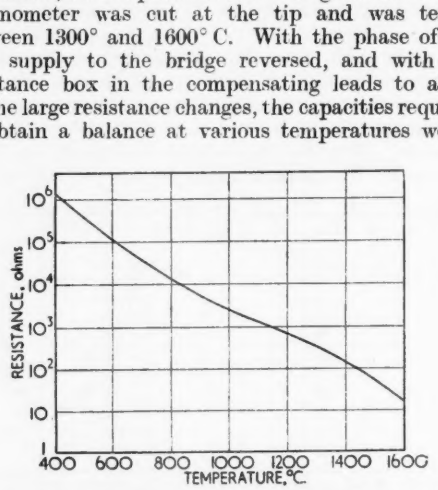

Fig. 7—Resistance/temperature characteristic of the magnesite thermistor

Instrument Setting	Extra Resistance, ohms	Temperature, °C.	Capacity, μF.
25·00	2500	1290	0·02
25·00	440	1380	0·05
25·00	100	1480	0·21
25·00	50	1560	1·84

At temperatures up to 1560° C. the furnace was under control to ± 1° C. for periods of some hours. Above 1560° C. the furnace tended to drift, probably because the thermistor had not been fired at a sufficiently high temperature.

To make use of a thermistor over a reasonable range of temperatures, some modification to the controller is entailed. The temperature range covered by the commercial instrument, using a thermistor having a characteristic similar to that given above, would be 1500–1575° C., *i.e.*, only 75° C. The addition of a resistance box increases the range to perhaps 300° C., but there is a loss in the sensitivity owing to the high ratios introduced in the bridge circuit. To increase this range further, and to reduce the loss of sensitivity, the potentiometer system of the controller must be removed and replaced by a resistance bridge having fairly wide ratios, *e.g.*, 1000 : 100 : 10 : 10 : 100 : 1000, which would work from 1 to 100,000 ohms. For good sensitivity, however, the safe range is probably not more than 3–30,000 ohms. By using this system a temperature range of 800–1600° C. can be covered satisfactorily, maintaining a good standard of control even when using a carbon-tube furnace. The authors have no doubt that on a platinum or molybdenum furnace the control would be just as accurate at 1600° C. as that obtained by normal methods at 1000° C.

CONCLUSIONS

(1) To obtain control of furnace temperatures to very fine limits, some form of proportional control is required.

(2) Of the three main types of proportional controller, which are : (i) the D.C. amplifier/reactor, (ii) the resistance thermometer/reactor, and (iii) the resistance thermometer/thyratron, each type gives excellent control, particularly type (ii), but only the resistance thermometer/thyratron type is available commercially.

(3) The commercial resistance thermometer/thyratron controller is designed to cover a range of 150–1100° C. The normal type of resistance bulb does not give satisfactory control when used on the instrument at temperatures above 800° C.

(4) The failure of these resistance bulbs is due to changes in the dielectric properties of the cement used to hold the platinum wire in position. As the temperature is increased the capacity of the bulb increases, and at about 800° C. is sufficient seriously to disturb the balance of the bridge and so cause loss of control.

(5) Three ways have been devised to overcome this trouble, and control of temperatures up to 1100° C. can be obtained quite easily by :

(i) Adding a variable condenser (0–1 μF.) across the 'ballast' resistor and using a cathode ray oscillograph to obtain the best possible setting at the required temperature

(ii) Using a modified resistance bulb in which the wire is threaded non-inductively through twin-bore refractory tubes and laid longitudinally to the main support tube. This method minimizes the contact between the wire and the refractory, hence the properties of the refractory are much less important

(iii) Using a cement such that no melt is formed in the temperature range required, thus ensuring that the capacity effect will be small. A magnesite cement has been developed which enables satisfactory control to be obtained over the upper limit of the controller (1100° C.), provided additional resistance is available to obtain a balance in the bridge network.

(6) Above 1250–1300° C. the magnesite resistance bulbs begin to act as thermistors, and except for a narrow temperature range within which they change over, they can be used up to 1550° C., or higher if suitably fired beforehand. To do this, since thermistors have a negative temperature coefficient of resistance, it is necessary to modify the commercial instrument to some extent.

(7) With the above modifications it has been shown that the controller is effective to better than ± 0·05° C. at 900° C. On the other hand, it has been found that a change of 15 V. in the mains input voltage causes a change of 0·5° C. in the level of the control (say from 900° C. to 900·5° C.) and fine temperature control over long periods can therefore be maintained only if the voltage of the supply is stabilized.

(8) By using a commercial resistance thermometer/thyratron controller and one of the new forms of resistance thermometer, accurate temperature control to better than ± 0·05° C. can be maintained up to 1100° C. Control to better than ± 1° C. on a carbon tube furnace, and probably to very much finer limits on a wire-wound furnace, can be obtained at temperatures up to 1600° C. by relatively minor modifications to the instrument.

Acknowledgments

The authors express their thanks to Mr. E. W. Colbeck, Metallurgical Director, Messrs. Hadfields, Ltd., for permission to publish this paper, and to all the members of the Research Department who helped in any way in this work, in particular Mr. J. O. Ward and Dr. W. F. Ford for their very valuable advice and assistance.

APPENDIX

Saturable Reactors

A saturable reactor[5, 6] is essentially a variable inductance, the variation being effected electrically and often electronically. If the core of an iron-cored choke is magnetically biased, its effective impedance falls rapidly as soon as the peak fields due to the A.C. current exceed that required to saturate the core. If the magnetic bias is sufficiently strong, the core will be fully saturated all the time and the inductance due to the core will be very small. Two limiting conditions therefore obtain : with no magnetic bias the full impedance is operative and the A.C. is a minimum, whilst with the bias sufficient to saturate the core the impedance is low and maximum current is allowed to flow. The magnetic bias is normally obtained by means of a D.C. winding on

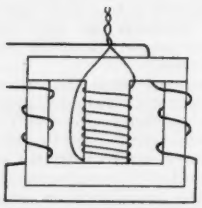

Fig. 8—Method of winding the power reactor

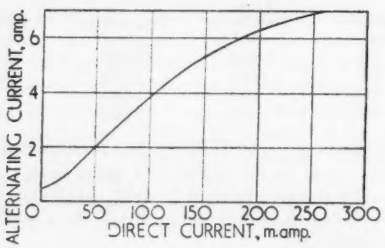

Fig 9.—Short-circuit characteristic of the reactor

the inductance, and it is essential that there is no A.C. interference with the D.C. circuit. The inductance must be wound so that the A.C. circuits do not generate any A.C. potentials in the D.C. winding. This may be effected, using the normal three-legged type of transformer laminations, by winding as shown in Fig. 8, that is, with accurately balanced A.C. coils on the outer legs, wired in series. In this way the A.C. fields generated in the centre leg are in opposition, and if they are properly balanced will cancel out each other. There is therefore no A.C. field in the centre leg, and hence a D.C. winding on this leg satisfies the conditions. A reactor built in this way will vary the current allowed to pass through the A.C. coils between wide limits, by the adjustment of the input to the D.C. winding. A reactor of this type, intended for the control of a 1-kW. furnace, was found to have the short-circuit characteristic shown in Fig. 9.

If, therefore, a means is available of automatically changing the D.C. field in proportion to, say, the temperature of a furnace heated by the A.C. passing through the reactor, a very sensitive and continuously variable control method is available.

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Metallography of Electro-Tinplate

By J. E. Davies, M.Sc., A.I.M., and W. E. Hoare, B.Sc.(Eng.), F.I.M.

SYNOPSIS

Samples of electro-tinplate from seven different sources have been examined by two metallographic techniques—oblique cross-sectioning and surface examination after de-tinning. Suitable methods of preparation of micro-specimens have been developed. A tin–iron compound layer identified as $FeSn_2$, has been observed in all flow-brightened samples. Study of commercial samples and laboratory-produced specimens indicates that the general crystallographic appearance of the tin–iron compound depends on the temperature reached in flow-brightening, on the time elapsing between fusing and quenching, and also on the orientation of the underlying ferrite grains.

Introduction

Electro-tinplate is produced by the electrodeposition of pure tin on mild-steel strip, in contradistinction to hot-dipped tinplate where the coating is produced by the immersion of mild-steel sheets in a bath of molten tin. The process of manufacture of electro-tinplate has already been well described,[1, 2, 3, 4, 5] but the metallographical structure of the coating has, so far, received little attention in the literature. The present study is intended to provide data that may assist the understanding of some of the problems involved in the manufacture and use of electro-tinplate. It also provides metallographic support for the coating-thickness determinations of Liebmann and others[6] who employed chemical and electrolytic dissolution methods.

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Mr. Davies was formerly a Research Investigator at the Tin Research Institute, Greenford, and Mr. Hoare is Head of the Tinplate Section.

Manufacture of Electro-Tinplate

The basic steps in the tinplating process comprise cleaning and pickling the strip, plating, flow-brightening, quenching, filming, and oiling.

Plating—Four types of electrolyte are in commercial use for plating—the acid electrolyte, which is a stannous sulphate phenolsulphonic acid solution containing an addition agent ; the 'halogen' electrolyte, which is a slightly acid solution of stannous chloride and stannous fluoride, also containing an addition agent ; the sodium stannate electrolyte, which is an

Table I

COMMERCIALLY PRODUCED ELECTRO-TINPLATE

Sample No.	Method of Manufacture: Electrolyte	Flow-brightening
1	Sodium stannate	Radiant heating (gas)
2	Sodium stannate	,, ,, ,,
3	Potassium stannate	Induction
4	Stannous sulphate	Conduction
5	Stannous sulphate	Conduction
6	Halogen	Induction
7	Halogen	Induction
8	Hot-dipped plate	

alkaline solution of sodium stannate ; and the potassium stannate electrolyte, which is an alkaline solution of potassium stannate.

Flow-Brightening—From all of the above electrolytes the tin is deposited as a mat or satin coating. The typical and desired bright finish of electro-tinplate is obtained by heating the as-plated strip to momentarily melt the coating, which is immediately quenched. Heating is provided by conduction,[3] (passing a heating current through the strip), by induction,[7] (passing the strip through a series of high-frequency induction heating coils), or by radiant heating,[8] in which case the strip passes between banks of focused hot-flame gas radiants.

Finishing Operations—After flow-brightening the strip is immediately quenched in warm water and the bright coating is then ' filmed ' in an oxidizing solution. Such solutions, which may be acid or alkaline, usually contain chromates and/or phosphates, and the protective oxide film may be produced by simple immersion or by electrolysis. After filming, the strip is usually oiled by applying a very thin coating of cottonseed oil or dibutyl sebacate. The oxide film and the oil layer are both thin and invisible and in no way detract from the bright pleasing appearance of the tinplate.

Speed of Operation.—The above operations and the various ancillary steps such as welding, rinsing, shearing, and inspection, are carried out on tandem lines which accept the coiled temper-rolled basis strip at the entry end and handle it as a continuously moving band until it is sheared to short lengths, classified, and piled at the exit end. According to the type of plating unit, nature of electrolyte, and coating-weight grade, line speeds may vary from approx. 200–1300 ft./min. A line is at present building which is designed to operate at 2000 ft./min.

Coating Thickness—Electro-tinplate is at present manufactured in three coating-weight grades designated as 0·25 lb., 0·50 lb., and 0·75 lb. per basis box. The basis box is the tinplate industry's unit of area (31,360 sq. in.) and the above coating weights thus correspond to coating thicknesses of approx. 0·000015 in., 0·00003 in., and 0·000045 in., respectively.

Electro-tinplate of 1·0 lb. per basis box, has been produced in fairly large quantities for experimental packs but has not so far reached the market as a commercially priced product.

Materials Used in Investigation

The commercially produced grades of tinplate used in this investigation are listed in Table I, and the results of chemical determinations of free tin and alloyed tin are given in Table II. A method involving the removal of the free tin in the coating by electrolysis and the subsequent removal of the alloy by dissolution in acid antimony trichloride was used.[9]

Identification of Tin–Iron Alloy Phases

One of the authors has shown[10] that the tin–iron alloy formed between the tin layer and the steel basis in hot-dipped tinplate is the compound $FeSn_2$. Other higher-iron compounds may be present, but the amount would be so small as not to be discernible

Table II

THICKNESS OF FREE TIN AND ALLOYED TIN IN TINPLATE SAMPLES

Code	Finish	Nominal Coating Weight, oz.	Free-tin, oz.	Alloy, oz.	Alloyed Tin, oz.	Total Tin, oz.
1*A*	As-plated	4	4·2	...	...	4·2
1*E*	Flowed	8	5·5	1·9	1·5	7·0
2*E*	Flowed	8	7·2	2·0	1·6	8·8
3*A*	As-plated	4	5·4	...	...	5·40
3*B*	As-plated	8	10·0	...	...	10·00
3*C*	As-plated	12	15·4	...	...	15·40
3*D*	Flowed	4	3·8	0·9	0·73	4·53
3*E**(*a*)	Flowed	8	6·1	1·1	0·89	6·99
3*E*(*b*)	Flowed	8	6·9	1·2	0·97	7·87
3*F*	Flowed	12	10·8	1·0	0·81	11·61
4*E*	Flowed	8	8·2	1·0	0·81	9·01
5*E*	Flowed	8	6·5	2·0	1·6	8·1
6*A*	As-plated	4	3·6	...	...	3·60
6*D*	Flowed	4	3·8	0·8	0·65	4·45
6*E*	Flowed	8	8·8	0·9	0·73	9·53
6*F*	Flowed	12	13·1	1·1	0·89	13·99
6*G*	Flowed	16	16·7	1·6	1·3	18·0
7*D*	Flowed	4	3·7	0·9	0·73	4·43
7*E*	Flowed	8	7·8	0·7	0·57	8·37
7*F*	Flowed	12	10·7	0·5	0·40	11·1
8	Hot-dipped	20	19·3	2·8	2·3	21·6

* Samples taken 1 yr. before other No. 3 samples

XUM

by the most refined micrographic means. However, alloy formation in electro-tinplate takes place under very different conditions and the practical absence of higher-iron phases in electro-tinplate could not be inferred from the previous study of the hot-dipped product.

It was felt desirable to find a better method of distinguishing between $FeSn_2$ and FeSn than by the differences in etching characteristics. These differences are small and not easy to develop even on bulk specimens[11] and would be impracticable for studying the ultra-thin laminae present in electro-tinplate coatings. The known crystallographic forms of the tin–iron compounds—$FeSn_2$ is tetragonal and FeSn is hexagonal[12]—suggested examination under polarized light as a possible means of distinction.

Three specimens of mild steel with composition C 0·09%, Si 0·013%, S 0·041%, P 0·046%, Mn 0·34%, Ni 0·68%, Cu 0·13%, and tin of 99·99% purity, were prepared as follows:

Specimen X—The steel rod was immersed in tin at 470° C. for 24 hr. and air-cooled. This produced a layer of $FeSn_2$ over the steel surface.

Specimen Y—A rod was immersed in tin at 600° C. for 24 hr. and then water-quenched. This treatment produced a layer of FeSn over the steel surface.

Specimen Z—A short length taken from specimen *X* was coated with iron-free alumina cement, placed in a nitrogen atmosphere furnace at 600° C. for 15 min., and cooled in the furnace. Under this treatment the original $FeSn_2$ layer formed a duplex layer with crystallites of FeSn lying adjacent to the steel surface.

Examination of these specimens under polarized light showed that FeSn responds by alternate lightening and darkening of each individual crystallite during rotation of the specimens between crossed nicols. The apparent reflectivity of $FeSn_2$ did not change with rotation of the specimen. These effects, which were observed in all three specimens, are well illustrated by the photomicrographs of specimen *Z* shown in Fig. 3.

METALLOGRAPHIC STUDY OF COMMERCIAL ELECTRO-TINPLATE

Two general methods of examination were employed, namely, cross-sectioning and surface examination.

CROSS-SECTIONING

Metallographic specimens were taken from areas closely adjacent to those used for the chemical determinations, and sections were cut so that the general plane of examination was at right angles to the direction of strip travel in tinning.

Because of the extreme thinness of the layers to be examined, oblique or taper-sectioning methods were used. Nelson[13] and Moore,[14] among others, have used such methods for the quantitative study of surface structure, and Klemm[15] employed the technique for the study of films and coatings. Hoare[10] developed a qualitative method, on similar lines, for studying hot-dipped tinplate.

In the present work a distortion ratio of about 10 : 1 was aimed at and the actual ratio for each specimen was determined by comparing the micrometered thickness of the tinplate (steel base plus coating), before mounting, with the apparent thickness measured on a × 10 macro-camera after mounting.

The oblique sectioning technique involves the following steps:

(*a*) Edge support by electrodeposition of copper or iron

(*b*) Pressureless mounting at room temperature in neutral-hardening Bakelite cement

(*c*) Oblique sectioning at angles of about 6°

(*d*) Surface grinding, emery paper polishing, diamond dust polishing, finishing with alumina.

Although the method has the advantage of magnifying the section width, it accentuates some of the problems normally encountered in mounting and sectioning tinplate—the method of supporting the edge of the tin coating; the design of the specimen holder; the technique of polishing.

Edge Support of the Tin Coating

Many experiments were carried out to determine the most suitable method of edge support for oblique sectioning. These included the trial of non-metallic supports and electrodeposited metal supports. Iron and copper electroplating were finally chosen as preferred methods. The technique adopted was as follows:

(1) Vapour degrease in trichlorethylene

(2) Cathodic clean, 15 sec. in hot metasilicate-trisodium phosphate–Calgon solution

(3) Plate to a thickness of 0·025 in. on each surface with copper or iron. Copper was plated by flashing in a cyanide bath followed by building up in an acid bath. Iron was plated from a chloride electrolyte under the following conditions:

Ferrous chloride,	375 g./l.
Calcium chloride,	187·5 g./l.
*p*H,	1·0
Current density,	60 amp./sq. ft.
Temperature,	90° C.

The majority of the authors' work has been carried out with iron-plated edge support since this is effective with different polishing techniques and etching media. Using copper-edge support it is essential to employ diamond dust for polishing and it is also advisable to use a nitric-acetic etching reagent in place of ferric chloride.

Mounting

Numerious mounting techniques were studied and

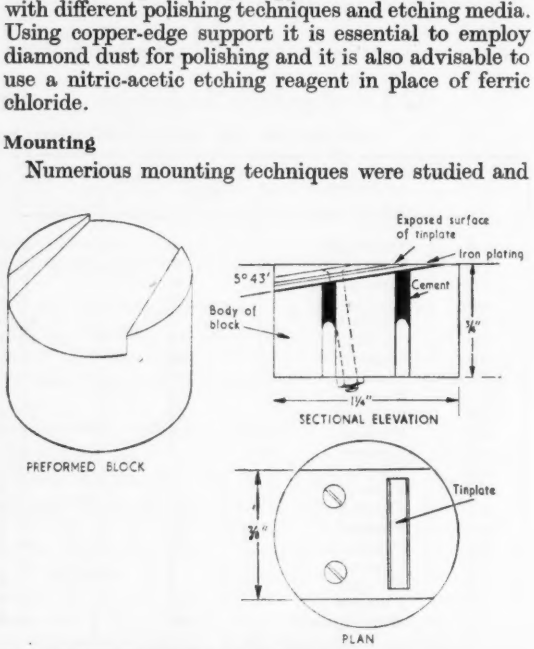


Fig. 1—Method of mounting specimen

the method finally adopted consisted of cementing the copper- or iron-plated specimen on to a specially shaped Bakelite block as shown in Fig. 1. A 1·25-in. dia. Bakelite block, 0·75 in high, was prepared in an ordinary metallurgical mounting press. By inserting a wedge-shaped shim in the bottom of the mounting die a tapered slot, equal in width to the specimen of tinplate, was formed in one face of the block. A 5° 43′ wedge-angle of the shim gave the desired distortion ratio of 10 : 1.

A 1·25-in. × 0·75-in. strip specimen, plated with 0·025 in. of iron or copper, was placed in position on the inclined face of the block, and two 8BA clearance countersunk holes were drilled right through the strip and the block. Several holes were then drilled through the block, and the inclined surface was shot-blasted to help key the cement. The strip was cemented to the block, using neutral-hardening Bakelite cement of the following formula :

5 parts by weight of cement *G*17613
1 part by weight of accelerator *Q*17618
0·6 part by weight of wood flour.

The cement was applied to the inclined face of the moulding, the strip was placed in position, two 8BA countersunk head bolts were inserted through the holes and the nuts were tightened off on the top face. The cement hardened satisfactorily at room temperature in 36 hr. In the method adopted the specimen was not subjected to undue pressure or temperature during mounting and the strip was firmly held at an angle of about 6° to the sectioning plane, giving the required distortion ratio of about 10 : 1.

Metallographic Preparation

The initial working surface was obtained by using a fluid-cooled tool-post grinder fixed to a precision lathe. A tool-post grinder is found to be a most useful adjunct in metallographic work in cases where full-scale surface grinding facilities are not available.

After experimenting with other methods, diamond dust[16] was finally adopted as the main polishing medium. The successive polishing steps used were :

(i) Durex 320 grit emery paper
(ii) „ 400 „ „ „
(iii) „ 500 „ „ „ or lead foil impregnated with *M*302 carborundum powder
(iv) Hubert 0 emery paper or lead foil impregnated with *M*303½ carborundum powder
(v) Rotating Selvyt cloth pad impregnated with diamond dust of ½–3-μ particle size
(vi) As (v) but with 0–1-μ diamond dust
(vii) 10–15-sec. light finishing treatment on Selvyt pad impregnated with alumina.

All diamond-dust polishing was carried out on a special 200-r.p.m., 5-in. diameter wheel using white spirit as a lubricant. Normally, polishing required 15–20 min. with the coarser dust and 5–10 min. with the fine dust. These times can be reduced to 5–8 min. and 2–4 min., respectively, by extending the emery-paper preparation as far as the 000 grade. Pressures used were slightly greater than for alumina-pad polishing and it was not found necessary to maintain a single polishing direction.

Etching reagents generally used were acid ferric chloride for the tin and 5% alcoholic picric acid for the steel. Specimens were examined in the unetched and etched conditions under ordinary illumination and with polarized light.

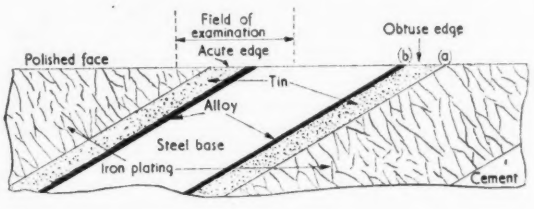


Fig. 2—Cross-section of oblique-mounted tinplate specimen

Examination of Specimens

A diagrammatic cross-section of an oblique-mounted tinplate specimen is given in Fig. 2. The left-hand coating section is called the 'acute' edge and the right-hand coating section, the 'obtuse' edge. A study of many specimens, with both iron and copper edge supports, showed that a true picture of the phases and layers present is depicted only at the acute edge. Spurious effects at the obtuse edge arise from weakness and tearing out of the very thin wedges of tin and alloy at the points (*a*) and (*b*) in Fig. 2.

Two typical microsections are shown in Figs. 4*a* and *b*. Both these specimens are nominal 8-oz. grade flow-brightened plate but the white band of alloy is considerably thicker in 1*E* (*see* Fig. 4*a*) than in 7*E* (*see* Fig. 4*b*). This is in general accord with the chemical determinations, and good correlation between the chemical tests and the metallographic pictures was obtained throughout (*see* Table III).

Figure 5 illustrates the effect of polarized light on the alloy layer and shows that, under polarized light, the alloy layer behaves in exactly the same way as artificially produced $FeSn_2$ and in the same way as the alloy layer in hot-dipped tinplate. This was confirmed by an examination of sections of all the specimens. This fact, coupled with the etching characteristics of the alloy layer, leads to the conclusion that the alloy layer in electro-tinplate is $FeSn_2$. The authors found no definite evidence of a higher-iron compound at the steel base–$FeSn_2$ junction although some slight effects, which cannot be interpreted and may be step-diffraction phenomena, have been noticed in some cases. It may be justifiably assumed, however, that the alloy layer in electro-tinplate is, for practical purposes, $FeSn_2$. Further evidence in support of this is given later (*see* p. 139).

Features of the Alloy Layer

Numerous discontinuities (pores) appear in the tin coating but, in the samples examined, the alloy layer appeared to be continuous across the bottom of the pore (*see* Fig. 6). This effect suggests that pores may develop during flow-brightening by retraction of tin from the $FeSn_2$ layer formed in the first stages of the operation. However, the effect was not studied sufficiently to make positive inferences.

Measurements of free-tin and alloy-layer thicknesses were made at 1500 diameters, both direct on the

Table III

METALLOGRAPHIC AND CHEMICAL DETERMINATIONS OF FREE-TIN AND ALLOY-LAYER THICKNESS

Sample	Thickness by Metallography, in. × 10^4		Thickness by Chemical Determination, in. × 10^4	
	Free Tin	Alloy	Free Tin	Alloy
1*E*	2·5	0·75	2·1	0·72
2*E*	2·7	0·72	2·7	0·76
3*E*(*a*)	2·6	0·50	2·3	0·42
5*E*	2·8	0·90	2·5	0·76
6*E*	3·6	0·35	3·3	0·34
6*F*	4·1	0·40	5·0	0·42
6*G*	5·9	0·68	6·3	0·61
7*E*	2·6	0·31	3·0	0·27

camera, and on photomicrograph negatives. Approximately 120 measurements were made on each grade listed in Table III, an overall average was obtained, and the true thickness was calculated from the distortion ratio and the magnification. Results, given in Table III, show that there was good agreement between the chemical and metallographic determinations.

SURFACE EXAMINATION

The progressive surface examination technique involves the following steps :

(*a*) Examination of the virgin surface under both macro- and micro-magnifications
(*b*) Anodic de-tinning with 5 or 10 % caustic soda solution
(*c*) Examination of the structures revealed under macro- and micro-magnifications.

Macro-Examination

The grain pattern of flow-brightened electro-tinplate is readily revealed by a 10-sec. etch in alcoholic ferric chloride solution. Coating grain size is generally very much smaller in electro-tinplate than in hot-dipped plate. Figure 8 illustrates grain patterns of electro-tinplate produced by flow-brightening by induction, conduction, and gas radiant heating methods. Although these structures can be considered as reasonably typical of the samples examined, it is known that the same general procedure of melting and quenching does not always produce the same grain picture. Quite wide differences of grain size and shape have been observed in samples which, from their history, would be expected to be similar. These variations in grain pattern are probably caused by local differences in melting and quenching conditions or conceivably by differences in plating conditions. They are unlikely to be very important in themselves, but they point to process variables, which may have some significance.

Micro-Examination

In the unetched condition the usual tin grain boundaries were visible. Coating discontinuities could also be readily discerned and in almost all cases an $FeSn_2$ layer was visible at the base of the pore (*see* Fig. 7).

One of the authors[17] had previously found partial de-tinning to be a useful technique for the study of local variations in coating thickness, and accordingly a short series of tests was made using this technique. The Francis thickness tester[18] was used and the conditions of test precluded attack on the alloy layer. The time for removal of all the unalloyed tin from a small selected area of a specimen was determined and then other areas on the same piece were de-tinned for one quarter, one third, and one half this time. Examination of these partially de-tinned areas showed, in all cases, that a larger amount of alloy was revealed than would be expected from an increase of exposed alloy at coating discontinuities.

In some cases the area of exposed alloy had no particular shape but in others (*see* Fig. 9) it showed up in lines parallel to the direction of tinning and rolling. These striations may be caused by excessive growth of alloy at certain localized points, for example, the hump in Fig. 5*a*. This striated effect was not observed with partially de-tinned as-plated specimens such as 1*E*, neither was it observed in laboratory-produced as-plated samples.

Micro-Examination of Alloy Surfaces

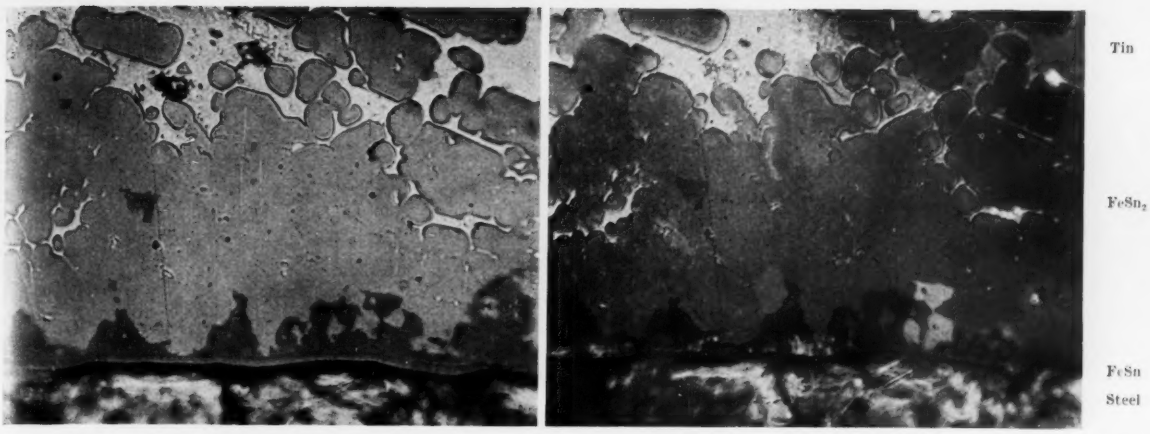
To study the alloy-layer surface after removal of the free-tin part of the coating, a de-tinning method must be used which is free from any attack on $FeSn_2$. The use of boiling alkaline sodium plumbite was rejected since this reagent has been found to attack the alloy layer slowly. Anodic dissolution of the tin in dilute caustic soda[18, 19] had been shown by Liebmann and Price,[6] using chemical means, to leave the alloy layer in electro-tinplate unattacked, and this has been confirmed by careful metallographic study.

A specimen of $FeSn_2$ was prepared by the method described on p. 136, a cross-section was prepared and an area was examined before and after anodic attack in the Francis tester. The total current used was 1·6 m.amp., which corresponded to the usual current density on the tin in normal de-tinning ; the voltage across the cell was 0·3 V., and the temperature was 17° C. The total time of attack, 660 sec., greatly exceeded that to which any alloy was likely to be subjected in normal detinning for micro-examination. The specimen before and after anodic attack is shown in Fig. 10. The tin has been deeply attacked while the alloy layer is completely unattacked (*see* Fig. 10*b*).

An examination of many alloy surfaces showed their structures to be of two general types. The first type, typified by Fig. 11, consisted of minute nodules and some very small rectangular crystallites in a dark and only partially resolvable matrix. In some of these specimens the alloy also showed an overall light and dark pattern, clearly visible in Fig. 11*b* and on which comment is made later (*see* p. 139).

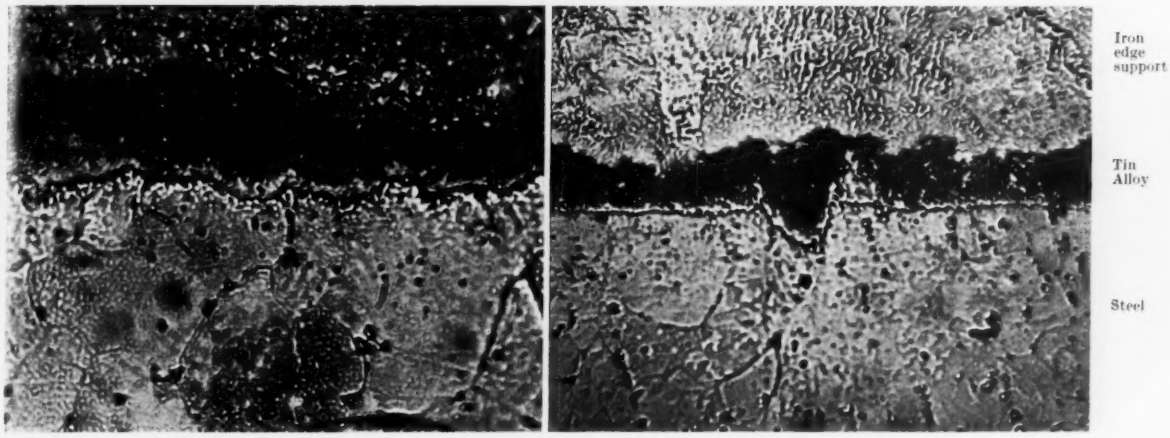
In the second type (*see* Fig. 12) the alloy layer appeared to be strongly duplex. Some areas were dark and on the borderline of resolvability, while adjacent areas were bright and characterized by a series of well-marked rectangular elevations or pits.

The light and dark areas of the duplex structure had fairly distinct grain-like shapes, which suggested that they might bear a relationship with the underlying ferrite grains. Accordingly, an area was identified



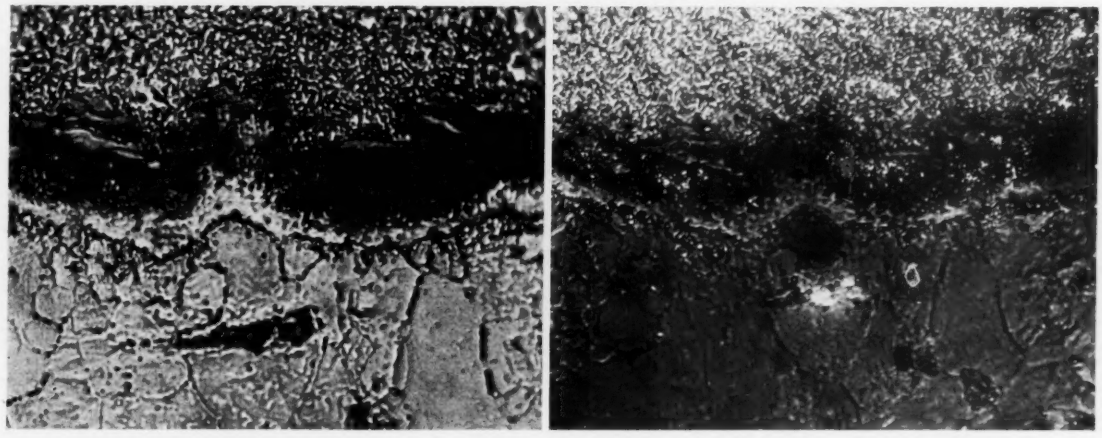
(a) (b)

Fig. 3—Photomicrographs of specimen *Z*: (*a*) Under ordinary illumination; (*b*) rotation between crossed nicols × 1250



(a) (b)

Fig. 4—Photomicrographs of 8-oz. grade flow-brightened plate: (*a*) Specimen 1*E*, D.R. 10·4, tin 5·5 oz., alloy 1·9 oz.; (*b*) specimen 7*E*, D.R. 9·4, tin 7·8 oz., alloy 0·7 oz. × 1500



(a) (b)

Fig. 5—Effect of polarized light on alloy layer: (*a*) Flowed 8-oz. plate (5*E*), D.R. 9·4; (*b*) same field as (*a*) between crossed nicols × 1500

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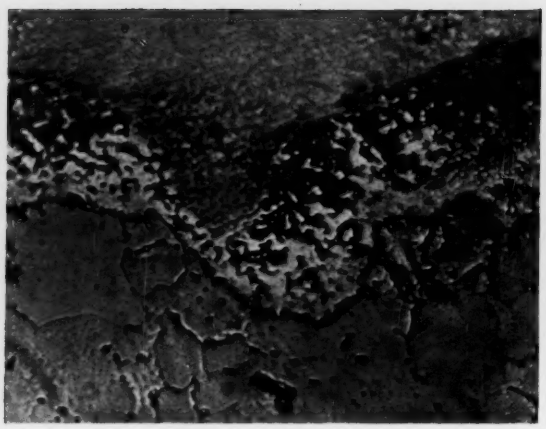


Fig. 6—Flowed 16-oz. plate (6*G*), D.R. 12·5, showing alloy at base of pore × 1500

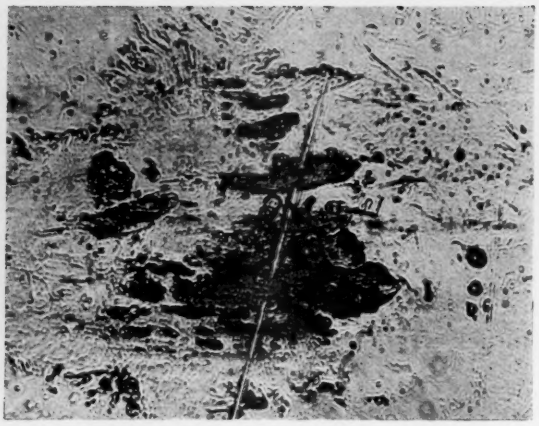
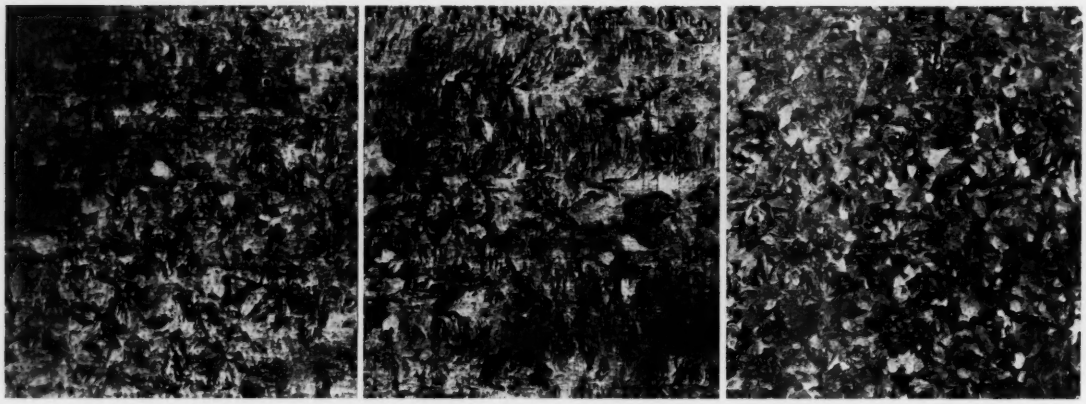
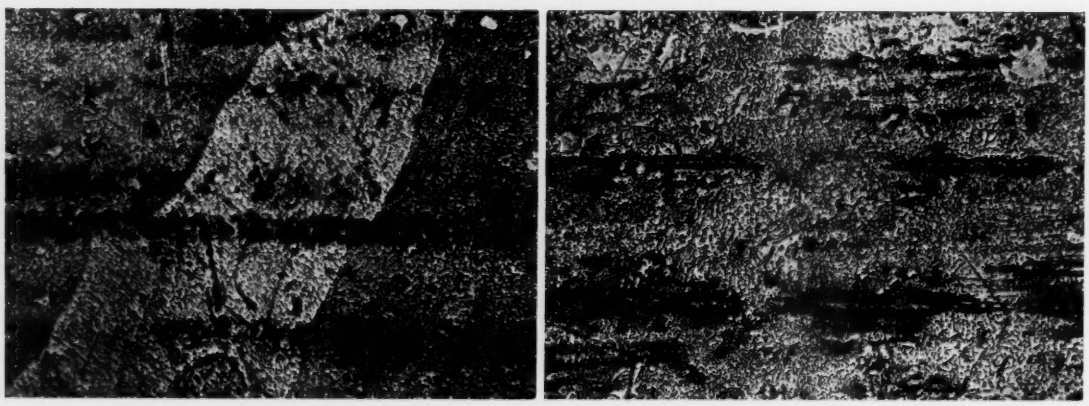


Fig. 7—Flowed 4-oz. plate (6*D*) showing discontinuity in coating with alloy at base × 250



(a) Induction-flowed 12-oz. plate (7*F*) (b) Conduction-flowed 8-oz. plate (5*E*) (c) Radiant-flowed 8-oz. plate (1*E*)

Fig. 8—Grain patterns in electro-tinplate × 2



(a) Specimen 1*E* (b) Specimen 4*E*

Fig. 9—One quarter de-tinned flowed 8-oz. plate × 500

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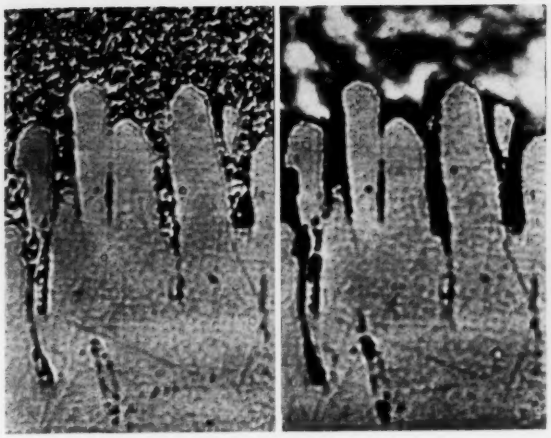
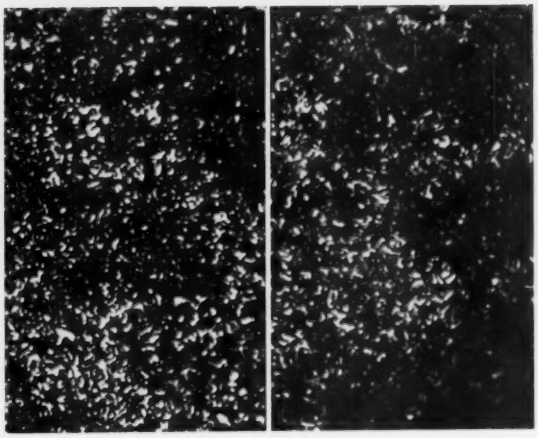


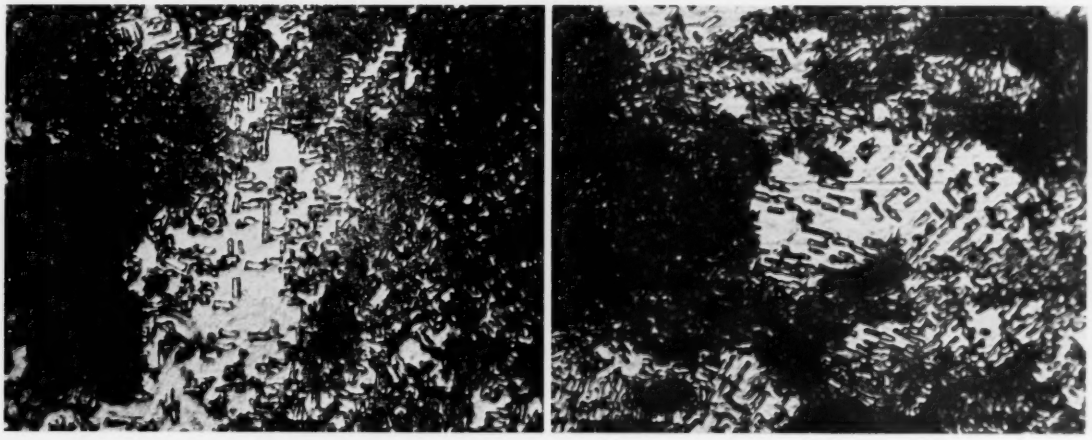
(a) As-polished (b) After anodic attack

Fig. 10—Area of $FeSn_2$ specimen × 1250



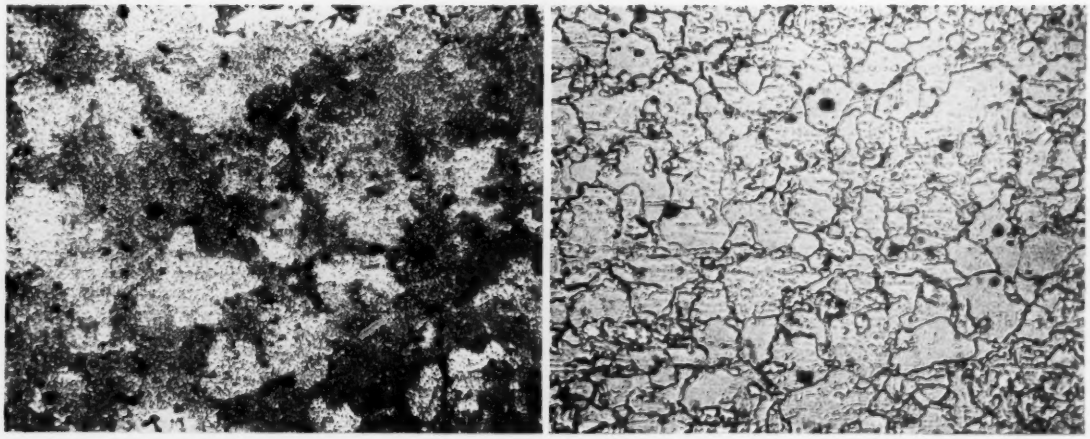
(a) Specimen 1*E* (b) Specimen 5*E*

Fig. 11—Alloy surface of flowed 8-oz. plate × 2000



(a) Specimen 6*D* (b) Specimen 7*D*

Fig. 12—Alloy surface of flowed 4-oz. plate × 2000



(a) Alloy layer intact (b) Underlying steel after removal of alloy layer

Fig. 13—Surface of flowed 4-oz. plate (7*D*) × 500

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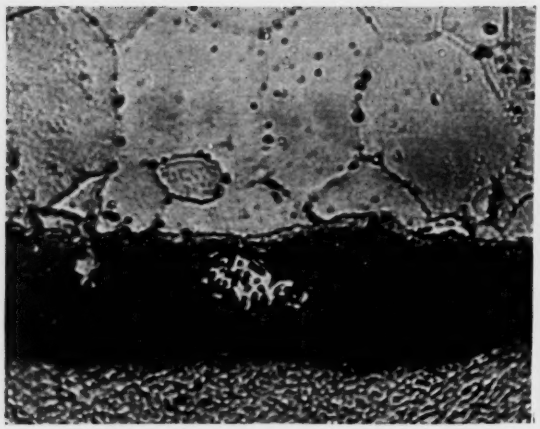


Fig. 14—Crystallites in oblique micro-section of flowed 8-oz. plate (6*E*), D.R. 7·2, tin 8·8 oz., alloy 0·9 oz. × 2000

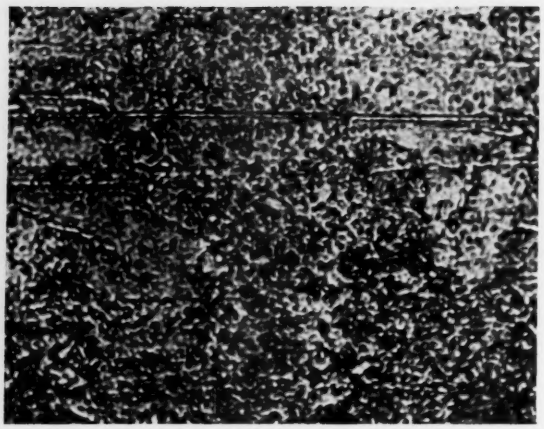


Fig. 15—Alloy surface produced by 10-sec. heat-treatment at 245° C. × 2000

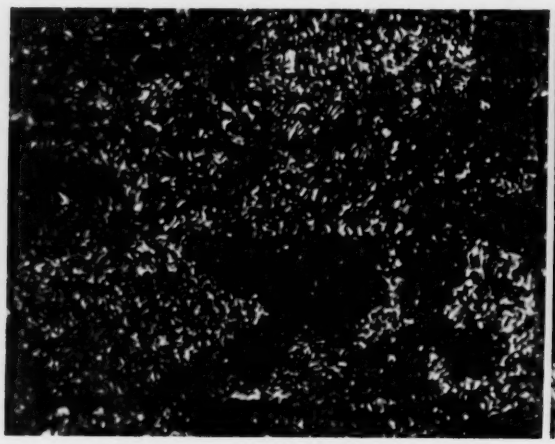


Fig. 16—Alloy surface produced by 2½-sec. heat-treatment at 270° C. × 2000

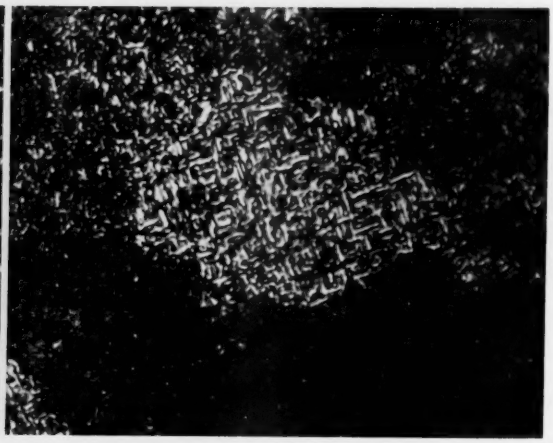
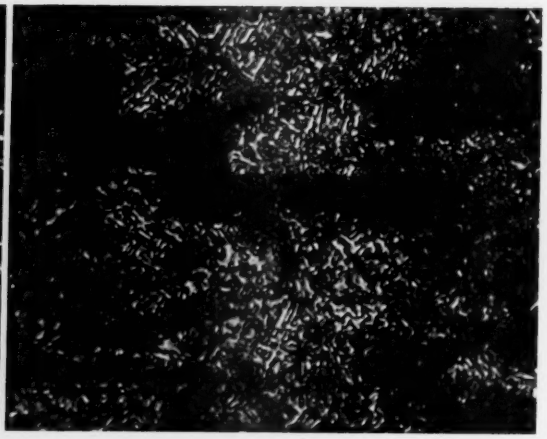


Fig. 17—Alloy surface produced by 1-sec. heat-treatment at 320° C. × 2000

(a) 10 sec. at 245° C.



(b) 20 sec. at 245° C.

Fig. 18—Alloy surface of induction-flowed 4-oz. plate after heat-treatment × 2000

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by making a shallow Vickers pyramid indentation close to it. The alloy surface was photographed, the alloy was removed with concentrated hydrochloric acid, and the underlying steel was etched with 2% nitric acid in alcohol. The results, illustrated in Fig. 13, show that the ferrite structure corresponded with the alloy structure. This is made strikingly clear by placing transparencies of the two photographs one over the other. This experiment was repeated with other specimens and similar results were obtained. The same effects were noted with the laboratory-produced samples discussed later.

The rectangular shapes existing in the light areas of the structure are undoubtedly crystallites of $FeSn_2$. Although they have somewhat similar appearance to etch pits there is good evidence that they are elevations and not depressions. Also it has been shown that etch pits cannot be produced in ferrite by the method of de-tinning employed. Typical crystallites may be observed in oblique microsections (*see* Fig. 14) where the taper enables crystallites to protrude through the thin wedge-like edge of tin.

A study of the various structures illustrated shows that the $FeSn_2$ crystallites tend either to be parallel or at right angles to each other in the same local area. This orientation may in turn be connected with the lattice of the underlying ferrite grains. Micrographic work is necessarily very limited in the volume of material it can survey, but it may be significant that the second type of alloy structure (Fig. 12*b*) was observed mainly in samples 6 and 7, which were manufactured by the same process although at different works. Although the alloy structures shown may be considered typical, quite considerable variations of structure were observed within the same specimen. These variations were, however, usually matters of degree.

LABORATORY STUDY OF ALLOY FORMATION

This section of the investigation was carried out alongside the main study of commercially produced electro-tinplate, and although further work is in hand a number of interesting points have arisen.

Rate of Alloying

To determine the rate of alloying of thin electroplated tin coatings on steel, small specimens were placed in aged palm oil at various temperatures and for various times and the amount of alloying was determined by chemical means supplemented by microscopic examination. The following procedure was generally used :

Sixteen coating-thickness determinations were made in random positions on each sample to be tested, using the Francis tester, and the average of these was taken as the tin-coating thickness before heat-treatment. A series of 1-in. squares was then cut from each specimen and 16 of these were used for each heat-treatment condition. To avoid loss of tin by gravitational drainage during flowing, the small squares were held horizontally in the molten palm oil and the final free-tin determinations were made on the upper face.

Oil temperatures used were 245° C., 270° C., 295° C., and 320° C., and it was found by experiment that on specimens 1 in. × 1 in. × 0·010 in. the tin coating melted after the following times :

245° C.	after approx.	7·5	sec.
270° C.	,,	2·5	,,
295° C.	,,	1·0	,,
320° C.	,,	1·0	,,

A preliminary test showed no evidence of alloy formation or growth at temperatures below the melting point of tin. For example, heating for as long as 20 sec. at 229° C. caused no measurable growth of alloy in an as-plated specimen. Rate and type of growth appeared to be unaffected by thickness of coating and, since good supplies of 4-oz. as-plated commercial electro-tinplate were available for comparative tests, most tests were carried out on coatings of this thickness (0·000015 in.).

Heat-Treatment of As-Plated Specimens

In the laboratory-plated specimens, cold-reduced tin mill base of composition C 0·08%, Si 0·010%, S 0·011%, P 0·031%, Mn 0·40%, Ni 0·035%, Cr and Cu trace, was used throughout. Commercial as-plated specimens were included in the test for comparison.

The alloy surface of a specimen treated for 10 sec. at 245° C. is shown in Fig. 15. Quantitative chemical determination gave a figure of 0·000003 in. (0·8 oz. basis). The amount of alloy is a little low compared with the average commercially flowed product (1·2 oz. basis). Heating for 2½ sec. at 270° C. gave an alloy layer as depicted in Fig. 16 (thickness 0·000004 in.). Heating for 1 sec. at 295° C. and 320° C. gave thicknesses of 0·000005 and 0·000008 in. respectively. The 320° C. specimen is shown in Fig. 17.

A short series of experiments was also carried out by heating already flow-brightened commercial samples. Typical results are illustrated in Fig. 18. The duplex area structure appears to form first (Fig. 18*a*) and as alloy formation proceeds the strongly defined character of the light areas is lost and the appearance of the alloy surface approaches that depicted in Fig. 18*b*.

It has often been stated that, in flow-brightening, the tin coating is heated to just above its melting point, but from a study of numerous compound structures the authors believe that the actual temperatures reached in commercial flow-brightening may be relatively higher and perhaps in the range 260–300° C.

SUMMARY OF RESULTS

The effectiveness of diamond dust as a polishing medium, resulting from its very high hardness compared with that of tin or steel, was confirmed. Disadvantages of certain other methods of preparation were avoided and the production of optically flat and scratch-free sections was facilitated.

The non-attack of the alloy layer by anodic de-tinning at room temperature in 5 or 10% caustic soda solution has been confirmed.

All the flow-brightened electro-tinplates examined showed a tin–iron intermetallic compound adhering

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to the steel base. Comparison of the etching characteristics of this compound and its behaviour under polarized light, with those of prepared samples of $FeSn_2$ and those of the known alloy layer in hot-dipped tinplate, indicates that the alloy layer in electro-tinplate is $FeSn_2$.

The alloy layer in flow-brightened electro-tinplate begins to form as soon as the tin coating melts. Heat-treatment of commercial electro-tinplates and samples electro-tinned in the laboratory, indicated the mode of formation and growth of the alloy. Up to the maximum temperature likely to be reached in production flow-brightening, the alloy appeared to form at different rates on different steel-base ferrite grains, depending on the orientation of these grains. The structure of the alloy depends on the temperature reached and the time elapsing between fusion of the tin coating and ultimate quenching.

When flowing temperatures were below 250° C., the alloy initially formed exhibited a rather characterless structure. In the range 260–320° C. the alloy initially formed, exhibited a duplex structure presenting an overall grain-like appearance, which bore a direct relationship to the steel-base ferrite grain structure. In the light areas minute rectangular crystallites of $FeSn_2$ were visible, which were probably orientated in relationship to the lattice of the underlying ferrite grains.

The effect of a long fusion time at 245° C. increased the amount of compound but did not produce the duplex type of structure. In the range 260–320° C., increase in the fusion time resulted in the light areas of the duplex structure, typical of formation in this range of temperature, developing into a darker and nodular type of structure.

Bearing in mind the amount and type of alloy formed under various conditions of temperature and fusion time and the fact that the maximum time of fusion employed in production flow-brightening may be about $\frac{1}{2}$ sec., it is considered that the actual temperature reached at the reacting interfaces during production flow-brightening may in some cases be as high as 300° C.

Acknowledgments

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The authors also wish to express their appreciation of the advice and encouragement given by Dr. E. S. Hedges, Director of Research of the Tin Research Institute, and to thank their colleagues, Dr. J. W. Price and Mr. K. W. Caulfield, for their help in certain phases of the investigation. Thanks are also due to Mr. E. C. W. Perryman, of the British Non-Ferrous Metals Research Association, for his valuable advice on the diamond-dust polishing technique.

The authors also thank the various manufacturers who supplied the electro-tinplate used in this investigation.

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OEEC COUNTRIES TO POOL BLAST-FURNACE RESEARCH

For the first time, several countries of Western Europe will share both the expense and the results of setting up large experimental industrial units for research on a new process for pig-iron production. As a result of the initiative taken by the Council of the Organization for European Economic Co-operation, interested countries will undertake, on a co-operative basis, the operation of two new blast-furnaces, at Liége in Belgium, and at Oberhausen in Germany.

The general technical direction of the trials at the new blast-furnaces will be undertaken by a Governing Board comprising representatives of all contracting countries. Similarly, the administrative and financial management will be undertaken by international managing bodies.

The new blast-furnaces will be of the low-shaft type, employing a tonnage oxygen blast in the manufacture of pig iron, for example, from low-grade or powdery ores, from ores of high-sulphur content (yielding sulphur-free pig iron) using small coke and mechanically weak coke, raw coal, or lignite.

Austria, Belgium, France, Germany, Greece, Italy, and the Netherlands have already indicated their intention to join in the scheme. The United Kingdom, without at the moment entering into the scheme as a contracting party, will make a financial contribution. Luxemburg and Canada are also considering contributing to the scheme.

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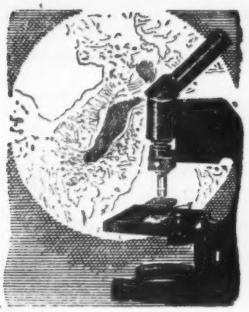

Magnetic Analysis of Iron–Carbon Alloys

THE TEMPERING OF MARTENSITE AND RETAINED AUSTENITE

By J. Crangle, B.Sc., and W. Sucksmith, D.Sc., F.R.S.

SYNOPSIS

During recent years, it has become apparent that the observation of structure-insensitive magnetic properties, particularly magnetic saturation intensity and its variation with temperature, leads to a useful method of investigating problems concerning metals. The method may often be applied where other techniques, such as X-ray diffraction, are less sensitive, and from its use quantitative information may be obtained about phases in alloys.

In the work described in this paper, the method is used to examine the phases involved when quenched pure iron–carbon alloys are reheated. Results indicate some magnetic properties of the phases, and their compositions. It is shown that during the first stage of the martensite breakdown a ferromagnetic phase different from cementite is precipitated : some of its magnetic properties are indicated. Retained austenite is found to change into the same state as does martensite. After heating to 300° C., cementite and another carbide with composition and magnetic properties similar to those of iron percarbide ($Fe_{20}C_9$), are found to be present.

Introduction

THE processes by which supersaturated solid solutions of carbon in iron regain the equilibrium two-phase state on reheating at temperatures below about 550° C. have considerable metallurgical interest. Their effect on the mechanical properties of the alloys has had wide commercial application, but as yet there has been no complete explanation of their mechanism.

The rapid quenching of a pure iron–carbon alloy from the high-temperature γ-phase solid solution (austenite) produces at room temperature an unstable phase (martensite) with a tetragonally distorted α-iron crystal structure, having carbon in supersaturated solution. This is usually mixed with retained austenite, the proportion of which depends on the composition and quenching conditions.

Kurdjumov[1] showed that with about 1% of carbon, martensite decomposed fairly rapidly above 50° C., precipitating the carbon in some unspecified form. Kurdjumov and Lyssak[2] found that even at room temperature the decomposition proceeded slowly, being effectively complete after ten years below 20° C. At the end, some carbon still remained dissolved, and heating to at least 300° C. was necessary for the α-solution to regain a state approaching the equilibrium composition (ferrite). Fletcher and Cohen[3] showed that it was not the equilibrium carbide, cementite (Fe_3C), that was predominantly precipitated, and Heidenreich, Sturkey, and Woods[4, 5] detected electron diffraction lines from an unidentified hexagonal structure. A similar structure has been observed in X-ray work by Jack,[6] who suggested from lattice parameter evidence that the precipitate is an iron carbide, of composition close to Fe_3C.

This paper describes work on the nature of the phases involved in the change from the quenched to the annealed state on reheating, using pure alloys. Measurements on the variation of magnetic saturation intensity with temperature were made, because this method is less sensitive to the effects of high stress and small crystallite size than are X-ray diffraction techniques. It is not possible to identify unambiguously one of the phases which occurs, for as yet there are no magnetic data for a wide composition range that is thought to exist in an iron carbide with

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Professor Sucksmith and Mr. Crangle are in the Physics Department of the University of Sheffield.

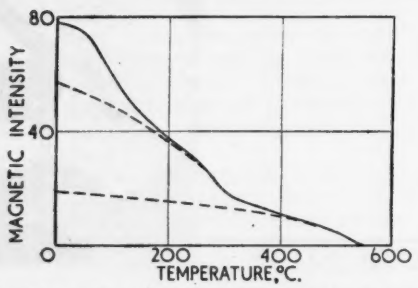

Fig. 1—The (σ, T) curve for a three-phase iron–silicon alloy (Guggenheimer, Heitler, and Hoselitz[9])

hexagonal structure. Owing to the probable instability of most of this range, it may indeed be found that these data cannot be obtained directly.

EXPERIMENTAL METHODS

Magnetic Methods of Phase Analysis

The saturation magnetic intensity and Curie point of ferromagnetics are structure-insensitive, unlike most low-field magnetic properties, which are affected by applied conditions. Previous work has shown that when sufficiently strong magnetizing fields are used, the relationship between its specific magnetic intensity (σ) and the temperature (T), characterizes a material, or a composition within a solid solution. Because of this property, the following ways of investigating alloy problems may be employed: (*a*) by observations of the change in intensity as a transformation proceeds, so measuring reaction temperatures and rates and finding to what degree the transformation is complete ; (*b*) analysis of alloys for the phases present, by examining the shape of (σ, T) curves of reaction products, measured under conditions of equilibrium or quasi-equilibrium, so that the curves are reversible. The first method has been widely used previously, often in cases where low magnetizing fields have prohibited the application of the second. This latter has been used in work on the iron–nickel[7, 8] and iron–silicon[9] systems.

Where the phases in a given alloy have constant composition, a qualitative analysis may be made by measuring their Curie points and comparing them with the known values for standard materials. Knowledge of the Curie point often gives the composition of variable solid solutions directly, and phase boundaries may be located by tracing the relationship between the compositions of individual phases and of the whole alloy. In this way, Hoselitz and Sucksmith[8] were able to determine the boundaries of the iron–nickel two-phase region, and to study the kinetics of reactions involved. Figure 1, taken from the paper by Guggenheimer, Heitler, and Hoselitz,[9] shows the intensity–temperature curve for an alloy made up of three ferromagnetic phases.

It was shown in these earlier investigations that in a multi-phase alloy, the observed intensity–temperature curve is the sum of the independent effects from the separate phases, combined according to their proportion. To analyse an alloy quantitatively, the known intensity values for various combinations and proportions of phases are fitted on to its (σ, T) curve over a wide temperature range. At a given temperature, each phase contributes to the total intensity an amount equal to the product of its specific intensity and its proportion by weight in the alloy. The sum of the contributions from all the phases is equal to the value measured experimentally. Using this principle, a set of linear equations may be formed, one for each of several temperatures. For maximum sensitivity it is advisable to choose for one the lowest convenient temperature, and for the others, temperatures just above the Curie point of each phase. Simultaneous solution of the equations gives the proportion of each phase present, and the result is unique, if no two phases have an identical (σ, T) curve. The intensity–temperature relationships of the phases present must be known ; this is simplified in the iron–carbon system by ferrite and two of the three known carbides having effectively constant composition. It is possible, because of the diluting effect of undetected non-magnetic material, for this analysis to show a total amount less than the whole alloy, but if the measured intensity is higher than the value that can be contributed by the phases known to be present, there must be additional ferromagnetic material involved. This technique has been used earlier in the phase analysis of iron–silicon alloys, and has given satisfactory solutions. To justify its application to the iron–carbon system, it was tested on annealed steels that had previously been analysed chemically.

The Measurement of Magnetic Saturation Intensities

Intensities were measured using the magnetic balance previously described.[10] This allowed work to be done in the temperature range 0–900° C., and at certain low temperatures in applied fields of up to 17,000 oersteds. The specimens were rough cylinders, weighing less than 60 mg.

All measurements were made relative to pure iron (Johnson-Matthey H.S. Brand) as standard. Its intensity per unit mass was taken as 217·7 e.g.s. units at 18° C. in a field (corrected for demagnetizing effect) of 15,000 oersteds.[11]

For most alloy specimens, intensities were measured in three applied fields of between 10,000 and 17,000 oersteds, to test that an approximation to saturation conditions always occurred in the specimens. Where the intensity at any one temperature was required, the value measured in the highest field was taken, and there was no attempt to extrapolate to infinite field ; a similar course was taken for measurements on carbides when in the free state. This was done because of the difficulty of estimating quantitatively the demagnetizing field for particles of precipitates of irregular shape, embedded in a matrix of iron. Only for the magnetically hard carbides is there much difference in intensity as the field is increased to infinity from the highest strength used ; since these always form much less than a quarter of the whole alloy, little error is introduced, and the procedure seems to be justified by the phase analysis results for annealed steels, which have been confirmed by chemical analysis.

Materials

(*a*) *Preparation*—Alloys of high purity are essential to avoid extraneous magnetic effects. They were

prepared by heating solid pure iron in carburizing atmospheres, applying a method similar to that of Mehl and Wells.[12] The gaseous atmospheres consisted of mixtures of hydrogen with various amounts of one or two of the hydrocarbons xylene, toluene, and dipentene ; the pure iron was either Johnson-Matthey H.S. iron, or low-oxygen pure iron from the National Physical Laboratory, Teddington. Reaction temperatures were usually within the range 1000° ± 100° C., the exact value depending on the final carbon content required, and times of treatment were about 16 hr. The iron was in the form of cold-rolled plates, about 15 mm. × 20 mm., × 1 mm. thick. Each had a small hole drilled near one end to enable it to be hung inside the carburizing furnace from a thin iron wire, thereby reducing the chance of impurity pickup by solid diffusion at the points of support.

(*b*) *Purity of the Alloys**—Spectrographic analysis of the alloys has shown the following impurity amounts for steels prepared from H.S. iron :

Impurities	Amount Present, %
Si, Mn, Ni, Mo, V, Co	< 0·01
W, Ti, Sn	< 0·02
Pb	< 0·05
Al	< 0·005
Cr, Cu	0·01

The source of the Cr and Cu impurities was later traced to contamination during the rolling of the iron to 1 mm. thickness, and in subsequent specimens care was taken to eliminate this effect. Chemical analysis showed P and S contents of 0·004%, and vacuum-fusion analysis gave the values $O_2 = 0·1\%$, $N_2 = 0·002\%$, and $H_2 = 1·9$ ml./100 g.

The main difference between the H.S. and N.P.L. iron is that the latter has oxygen and nitrogen contents of about 0·001%.

(*c*) *Homogeneity of the Alloys*—Metallographic examination of the carburized plates was carried out after cutting along a transverse section. Most specimens appeared to have carbide uniformly distributed across the thickness, and those that were non-homogeneous were rejected. In some with high carbon content, prepared from H.S. iron, free ferrite associated with massive free cementite occurred, possibly through the effect of oxygen impurity. During the subsequent magnetic work, however, no dependence on oxygen content of either saturation intensity or reaction temperatures was detected.

(*d*) *Heat-Treatment of the Alloys*—The specimens for the magnetic measurements, cylinders 1·9 mm. in dia. and 3 mm. in length, were cut from steels in the carburized condition. Because the plate thickness was never much more than 1 mm., specimens were made in two parts, divided along a central plane parallel to the cylinder axis. They were then quenched directly from temperatures in the γ-phase region. Specimens were not usually used for more than one series of measurements, and were thus not often quenched more than once. An apparatus was used in which the steel could be heated *in vacuo* in a tiny furnace to any required temperature up to 1150° C.

* Analyses, except for the estimation of oxygen, nitrogen, and hydrogen, were carried out by arrangement with B.I.S.R.A. at the Naval Ordnance Inspection Department Bragg Laboratory, Sheffield.

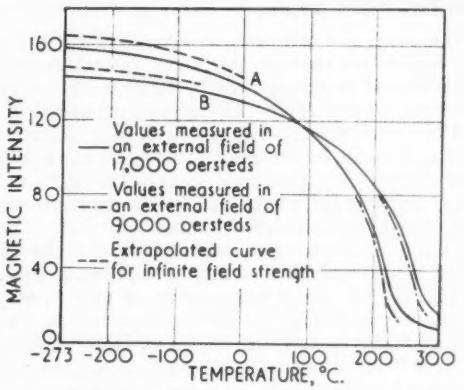

Fig. 2—(σ, T) curves for cementite (*A*), and iron percarbide (*B*)

To quench, cold water was quickly let into the vacuum, flooding the furnace and carrying the specimen to a cooler place : because of the small specimen size, the cooling rate was great enough, even for very pure alloys, to produce at room temperature a martensitic structure throughout the specimen, without any trace of cementite. The technique caused little oxidation or decarburization to occur. In cases where the minimum of retained austenite was required, the specimen was immersed in liquid air immediately after quenching.

Tempering treatments were carried out *in situ* in the furnace attached to the magnetic balance, to allow the accompanying changes in magnetic intensity to be followed directly.

IRON CARBIDES

As the phases in addition to ferrite involved in the tempering process in pure iron–carbon alloys must be all iron carbides, a summary of some known properties of these carbides is included.

Cementite (Fe_3C)

This is the most stable of the known iron carbides. Reported Curie points, mostly measured in weak fields, range from 205° to 220° C., probably owing to the presence of metallic impurities in material obtained from different sources. There has been no experimental proof that cementite can have a variable carbon content. Its properties are not affected by nitrogen, for although this seems the element most likely to replace carbon in the cementite structure, Jack[13] found no such effect.

The (σ, T) graph obtained for a sample of cementite extracted electrolytically from one of the pure iron–carbon alloys prepared during the course of the work described in this paper is shown in Fig. 2. It is in good agreement with the results for lower temperatures published by Guillaud.[14] Material prepared by carburizing iron oxide with carbon monoxide,[15] and also by thermal decomposition of iron percarbide, showed the same Curie point. Some cementite extracted from a commercial steel, and known to contain 0·75% of manganese as impurity, showed a slightly lower Curie point of 207° C. (measured in a 9000-oersted field).

Iron Percarbide ($Fe_{20}C_9$)

This name and composition were ascribed by Jack[16] to a higher iron carbide, the X-ray diffraction pattern of which was first recognized by Hägg.[17] The composition may vary slightly. The crystal symmetry is low and the structure has not yet been fully determined. Iron percarbide in the free state breaks down to form cementite at temperatures above 450° C.,[13] and it reacts fairly rapidly with free iron to produce cementite at temperatures above about 250° C.[18]

The (σ, T) graph for a sample prepared by Dr. K. H. Jack, containing 31·0 at.-% of carbon, is included in Fig. 2. The Curie temperature of 270° C. may be compared with those of 265° C. reported by Pichler and Merkel,[19] and 247° C. found by Hofer, Cohn, and Peebles,[20] both measured in weak magnetizing fields. The magnetic intensity at room temperature is near the rough values given in earlier work.[20]

Hexagonal Iron Carbide

An iron carbide with hexagonal structure has been observed in work on catalysts for the Fischer-Tropsch process of hydrocarbon synthesis, by Halle and Herbst (reported by Pichler and Merkel[19]), and by Hofer, Cohn, and Peebles.[20] A suitable name for this is ε-phase iron carbide, consistent with the nomenclature of the equivalent iron–nitrogen phase. These last workers obtained the carbide by carburizing finely divided iron (made by reducing an iron compound in hydrogen) with carbon monoxide at 188° C., in the presence of copper. Their sample contained an amount of carbon equivalent to Fe_2C, of which not less than 80% was in combined form. The Curie point was given as 380° C., a figure coinciding with that given by Pichler and Merkel[19] for a carbide prepared under similar conditions. All samples so far reported have been stabilized by the presence of some other element, such as copper, but it is unlikely that for pure material the Curie point will differ by more than a few degrees.

It was observed[19, 20] that this carbide began to decompose into iron percarbide ($Fe_{20}C_9$) at a temperature of about 300° C., in spite of the presence of the stabilizing elements. In comparison with the hexagonal ε-phase in the iron–nitrogen system,[21, 22] and with ε-iron carbonitrides,[16] the hexagonal carbide is expected to have a wide composition range ; the upper limit of the nitrides is at Fe_2N. It is not impossible that if compositions exist in this phase with less carbon than $Fe_{20}C_9$, they will form cementite directly on thermal decomposition.

RESULTS

The Reheating of Quenched Alloys

Figure 3 shows a typical curve for the variation of magnetic intensity with temperature as a previously quenched high-carbon steel is reheated. Three strongly marked irreversible changes occur. The first, near 100° C., is caused by the production of a state less strongly magnetic than the quenched martensite : the second change, near 200° C., is generally held to be the transformation of non-magnetic retained austenite into some ferromagnetic condition : the third change takes place slightly above 250° C. in pure materials, but apparently at a somewhat higher temperature in steel of commercial purity ; it causes a decrease in magnetization which is appreciable at this temperature, but is small at room temperature.

These changes are well known, and are linked with corresponding effects in some other physical properties of the alloys. They can take place over wide ranges of temperature, but occur more slowly at lower temperatures.

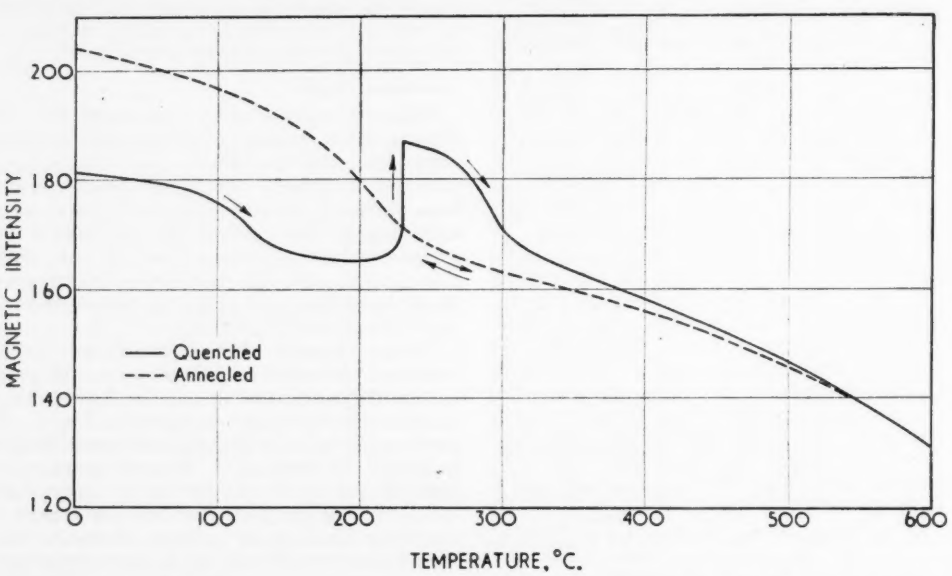

Fig. 3—Comparison of the (σ, T) curve obtained while reheating a quenched high-carbon steel, with that for the annealed state. (Heating rate uniform throughout, except at the second tempering stage, where the temperature was constant)

The First Tempering Stage

At the first stage of tempering, as well as the fall in magnetic intensity which characterizes the stage, it is found that when the specimen is cooled far enough to stop the reaction, the reversible part of the (σ, T) graph has become steeper than would be observed if only iron diluted with non-magnetic material were present. Figure 4 illustrates this effect. Since it is known from earlier density and X-ray diffraction experiments, such as those of Kurdjumov,[1] that ferrite and another phase are produced at this stage, it follows that this second phase is ferromagnetic, with its Curie point appreciably below that of iron. The observed steepening of the curve cannot be caused by the reduction in the amount of carbon dissolved in the iron affecting its Curie point, for, in the quenched state, where the most carbon is in solution, the (σ, T) graph is exactly as expected for iron diluted with non-magnetic retained austenite.

It is impossible to measure directly the Curie point of the first-stage precipitate ; further irreversible changes occur in the alloy at a lower temperature. Some idea of its magnetic properties may be obtained, however, by examining the relationship between the observed shape of the reversible part of the (σ, T) graph and that which might be expected, when various compositions are assumed for the precipitate. The method of carrying out the estimation is outlined in the appendix ; a typical result, obtained using numerical data taken from Fig. 4, and showing the dependence of the Curie point on the composition assumed for the precipitate, is given in Fig. 5. From the graph it may be seen that if the composition of the precipitate were Fe_3C (6·68% of carbon by weight) the Curie point would be at nearly 400° C. ; if it were Fe_2C (9·71% of carbon by weight), the Curie point would be at roughly 300° C.

The Second Tempering Stage

For steels containing 1·7% of carbon, the magnetic intensity at room temperature immediately after water quenching is about half that for pure iron, indicating the presence in this state of roughly equal amounts of martensite and retained austenite. For such specimens, the second stage begins slowly near

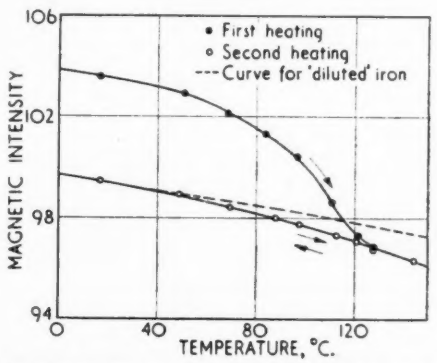

Fig. 4—The (σ, T) curve measured during and after the first tempering stage in a steel containing 1·72% of carbon

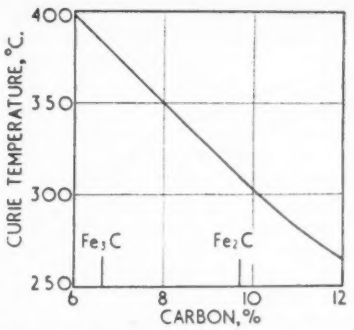

Fig. 5—Curve showing dependence of the calculated Curie point for the first-stage precipitate on the composition assumed for it

150° C. ; the main characteristic is an irreversible increase in magnetization, which can occur isothermally, and which is more rapid at higher temperatures.

To obtain the series of curves shown in Fig. 6, the specimen was cooled to room temperature at various stages in the transformation, and the intensity was measured afterwards, while reheating. All the lower curves, for which the specimen had not been heated far above 200° C., coincide within the limits of experimental error over the whole temperature range, when scaled up in inverse proportion to their intensity values at one temperature; this shows that all correspond to the same constitution in the ferromagnetic part, and differ from each other only in the proportion of retained austenite. Retained austenite decomposing below at least 200° C. produces, therefore, the same state as would martensite of the same composition when heated to like temperatures. There is no evidence to show the momentary existence of martensite during the transformation, but it may be significant that X-ray diffraction lines of decomposing retained austenite show no broadening or displacement, but only become gradually weaker. This conclusion agrees with the suggestion by Cohen,[23] based on metallographic evidence and the reaction kinetics, that the products of decomposed martensite and retained austenite are the same.

When the breakdown of the retained austenite is nearly complete, and it is necessary to exceed a temperature of 200° C. by an appreciable amount to promote the change, the (σ, T) curves become steeper than in the earlier stages. At the same time, there appears in the curves a weak inflection just above 200° C., at the Curie point of cementite ; this may be recognized by measuring the intensity changes for constant temperature intervals, and plotting them against temperature. A curve measured at the end of the second stage, drawn on a larger scale than the highest curve of Fig. 6, for a specimen of similar composition is shown in Fig. 7 ; the characteristics are typical of those observed for many specimens. It is, therefore, concluded that a small amount of cementite is being produced : its formation may be by further precipitation from the martensitic solution by a process different from that of the first stage. It is unlikely that the effect is caused mainly by a transformation product of the retained austenite, for

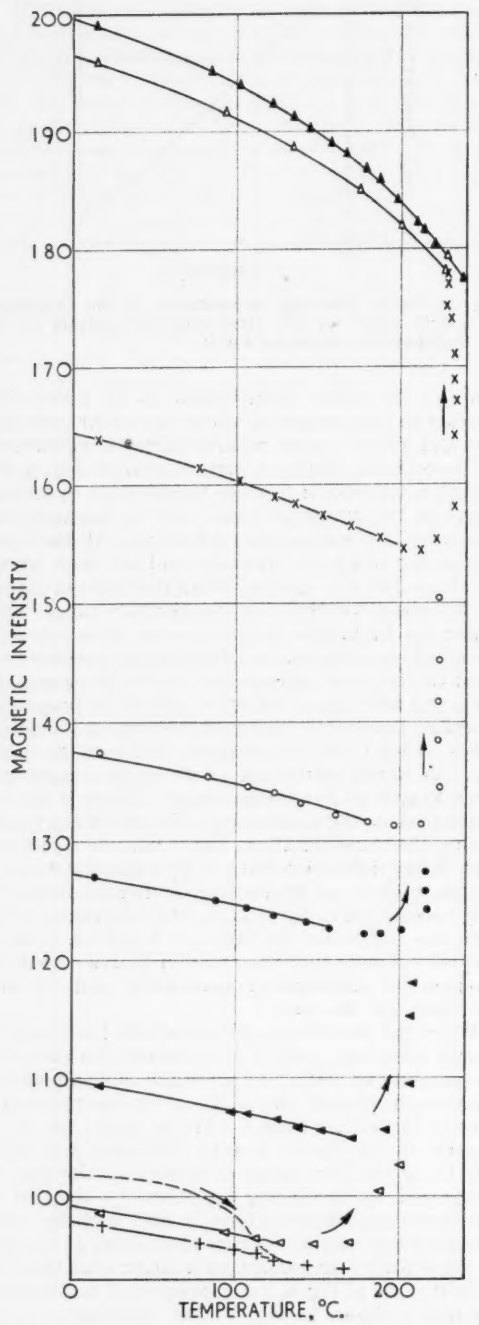

Fig. 6—(σ, T) curves measured at different stages in the transformation of retained austenite. The full curves are for reversible conditions ; the broken curve is as measured before the end of the first stage. Where irreversible changes occur, the experimental points are not joined

it was observed in many specimens that contained initially between about 1% and 50% of retained austenite.

The Influence of Carbon on the Saturation Intensity of Martensite—By comparing the intensity at room temperature at the end of the second stage with the corresponding value measured immediately after the first, a measure of the quantity of retained austenite present in the quenched state may be obtained. This gives information on the proportion of martensite formed during quenching, and on its specific intensity. The calculation is approximate, because of the unknown effect of the cementite formed at the end of the second stage on the intensity as measured, but by using a specimen containing the minimum of retained austenite to reduce the treatment times, the error may be minimized. Values for a steel containing 0·84% of carbon are as follows :

Intensity at 20° C.	c.g.s. Units
In the quenched state	204·3
At the end of the first stage	199·2
At the end of the second stage	211·0

The approximate proportion of retained austenite at the end of the first stage is 5·6%, so that the fraction which is martensite in the quenched state is about 94·4% ; the specific intensity of martensite with this composition is therefore 216·4 c.g.s. units. The value would be 215·8 c.g.s. units if dissolved carbon acted by simple dilution on the saturation intensity of iron. Other specimens with initially much higher retained austenite contents often gave results somewhat lower than those calculated assuming a dilution law, probably owing to the errors arising from the cementite formation mentioned before. The solution of small amounts of other elements in substitutional alloys with iron causes the magnetic intensity to follow a simple dilution law in all known cases. In the calculations it has been assumed that this holds for every composition considered.

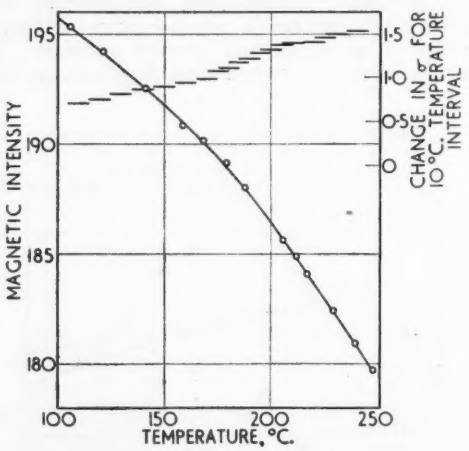

Fig. 7—Part of the (σ, T) graph for a high-carbon steel, measured after completion of the second tempering stage; the upper curve indicates the dependence of gradient on temperature

The Third Tempering Stage

When a quenched steel is tempered at just above 250° C., its magnetization falls irreversibly, at a rate which decreases with increasing time. Where the change becomes very slow, however, the magnetization is considerably different from that for equilibrium ; it is higher by an amount many times as large as the experimental error (*see* Fig. 8). This difference arises from two separate causes. Firstly, as well as the cementite Curie point just above 200° C. there is another at a somewhat higher temperature, but below 300° C. ; secondly, when the temperature is raised above the region where the phases with Curie points below 300° C. can contribute appreciably, the intensity is still higher than for the equilibrium state. While this latter difference has been observed previously[24] there seems to have been no earlier realization of its significance, possibly owing to the previous use of conditions removed from magnetic saturation, so that spurious effects of the same order were possible.

The curve shown in Fig. 8 for a high-carbon specimen after tempering at about 300° C., possesses the characteristics of multiple Curie points. Its long fairly straight portion *AB** is a fortuitous consequence of the combination of portions with positive and negative curvatures, belonging to two (σ, T) curves suitably disposed. If gradient is plotted against temperature, the start of one inflection at slightly above 200° C., at the cementite Curie point, and of another ending near 270° C., presumably at the Curie point of another iron carbide, may be seen. As the tempering temperature is raised above 300° C., the effect at the cementite Curie point grows and that at the other decreases, until in the annealed state only that of cementite is evident.

It seems certain that the precipitate is in fact non-homogeneous, and it is not merely that the tail of the (σ, T) graph of cementite has become extended : there is no experimental evidence that stress or a fine state of division can modify the tail in this way. Subtracting from the measured curve the ferrite contribution, estimated from the intensity above 300° C., gives a resultant curve quite unlike that expected for cementite ; it is considerably less steep, even at room temperature.

When the quenched specimen is heated to temperatures above 300° C., its magnetization approaches that of the annealed state in a way that appears to depend on temperature, but only slightly on time, finally meeting it at a temperature above 500° C. ; this is simultaneous with the reduction in the multiple nature of the lower Curie points previously described. If, by rapid heating, the main third stage is displaced to higher temperatures and is then allowed to occur isothermally, there is at first a quick change to a limiting value, beyond which the magnetization falls only slowly. The rate of the slow change increases with rising temperature, but even at 400° C., extrapolation of the intensity–time graph shows that the equilibrium state will not be reached in less than ten weeks. The two-stage nature of the effect suggests that there are two separate processes taking place simultaneously at different rates.

As the magnetization above about 300° C. is higher in the quenched and tempered condition than when the specimen is annealed, the alloy has a different constitution in the two states : the increased magnetization in the former cannot arise from experimental conditions, for all possible effects would make the apparent magnetic intensity lower than the true one. To test whether the difference could result from the presence of an additional phase with an appreciably higher Curie point than cementite, a quenched specimen with 1·7% of carbon was tempered at certain temperatures in the 300–500° C. range, and accurate intensity measurements were made between 300° C. and the tempering temperature. Comparison of the graphs produced (*see* Fig. 9) with the graph for the annealed state shows that, except where there are tail effects from the lower Curie points, the lines are parallel within the range of experimental error, even at temperatures as high as 495° C. (the relative error in intensity here is about $\pm 0{\cdot}1$ c.g.s. unit). An attempt to reduce the tail effects by using weaker magnetizing fields failed, because of the lower experimental accuracies attainable in such fields. This observation can be satisfactorily explained only if there is more free iron present in the quenched and tempered condition than when the same specimen is annealed. No known iron carbide possesses a Curie point so high as to make it indistinguishable magnetically from ferrite at 500° C., and such a phase could not be a residual first-stage precipitate, for this has an appreciably lower Curie point than iron (*see* p. 145, and Fig. 4).

The presence of more free ferrite in the quenched and tempered state than when there is equilibrium implies that after tempering there must be less carbide present than in the annealed state. Since the total carbon content is fixed, either the ferrite or the precipitate must contain more carbon than when the alloy is in equilibrium. Free carbon cannot be present, for earlier work has shown that a mixture of iron and graphite is more stable than one of iron and cementite, and cannot re-form cementite in the temperature range 300–550° C. Whether the excess carbon lies in the matrix or in the precipitate cannot be deter-

* Because this figure is reduced for reproduction, the long straight portion is not shown clearly ; in Table II, however, intensity values for the corresponding curve for another steel are given ; these may be replotted on a larger scale.

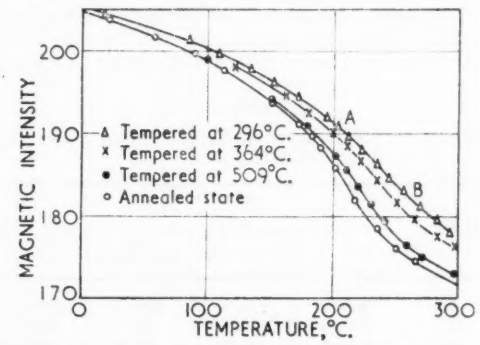

Fig. 8—The effect of tempering above about 300° C. on the (σ, T) curves measured below this temperature

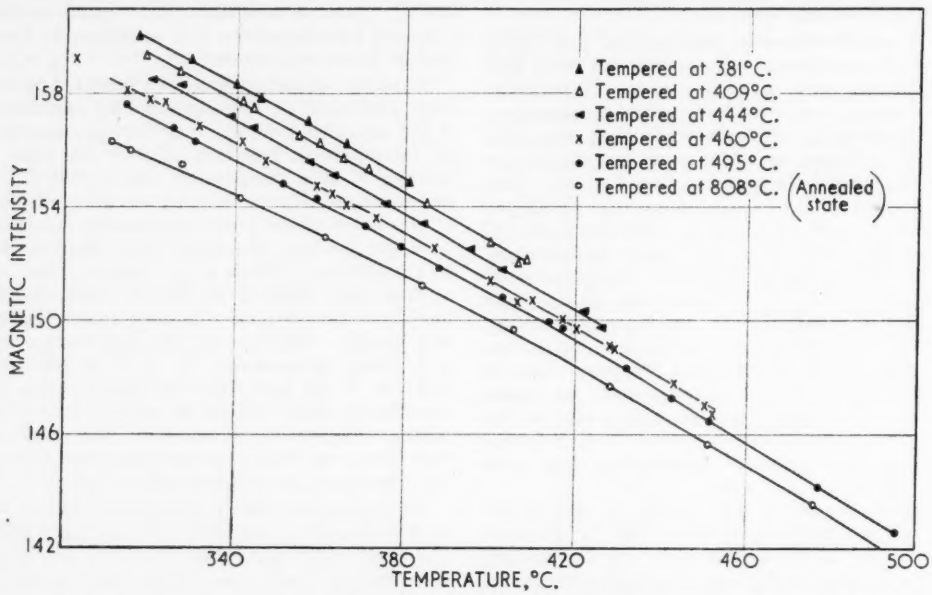

Fig. 9—(σ, T) curves measured above 300° C. after tempering between 300° C. and 500° C.

mined directly by the magnetic method. To explain the observations, either the matrix must still retain in solution at least 0·2% of carbon, or the whole precipitate must have an average carbon content of not less than 7·7%. The X-ray investigation by Kurdjumov and Lyssak,[2] who used single crystal techniques, suggests, however, that after tempering above 300° C. less than 0·05% of carbon still remains dissolved in the ferrite. If the results of their work are applicable to this case, it must be the precipitate which holds the extra carbon, and the increased magnetization above 300° C. must be caused by the presence of an iron carbide with a greater carbon content than the equilibrium precipitate, cementite. Since it is known that some cementite is present in this state, the precipitate must consist of a mixture of cementite with another iron carbide containing more carbon. Thus the carbide phase of which the Curie point lies between that of cementite and 300° C. contains more than 6·68% of carbon.

The state produced by tempering to the end of the main third stage was analysed quantitatively by calculations of the type described earlier in this paper. Because of the similarity in Curie point between the second carbide present and iron percarbide ($Fe_{20}C_9$), the (σ, T) data for the latter were used. Only a figure related to the true amount by some factor of proportionality can be obtained for the second carbide precipitate, since the scale of its intensity values is unknown. The calculated amounts of the phases identified with certainty, cementite and ferrite, should be correct, however. Several iron carbides, carbonitrides, and nitrides have reduced intensity–temperature curves (*i.e.*, curves obtained by plotting the ratio of the intensity to its value at the absolute zero against the ratio of the absolute temperature to the absolute Curie temperature) with very similar forms. It is unlikely that the carbide in question (not necessarily iron percarbide) will have a curve so different from the others as to make the calculation completely inaccurate.

A typical calculation for a specimen containing 0·84% of carbon, tempered at about 300° C., is as follows :

If c and f, respectively, are the fractions of cementite and ferrite present, and x equal to y/n is the fraction of other carbide (where y is the equivalent amount of iron percarbide required to fit into the measured curve and n is a constant), the following equations may be formed from the data in Table I :

$$\begin{aligned} 134{\cdot}8c + 128{\cdot}7y + 217{\cdot}6f &= 209{\cdot}2 \\ 19{\cdot}8c + 58{\cdot}7y + 208{\cdot}8f &= 192{\cdot}5 \\ 9{\cdot}0c + 18{\cdot}4y + 205{\cdot}8f &= 186{\cdot}4 \end{aligned}$$

These are satisfied by the solutions :

$$\begin{aligned} c &= 0{\cdot}03_0 \\ f &= 0{\cdot}89_7 \\ y &= 0{\cdot}07_6 \end{aligned}$$

As a check, intensities at several temperatures were calculated from the solution and compared with the measured values. The comparison is shown in

Table I

INTENSITY VALUES FOR THE PHASE ANALYSIS CALCULATION*

Temp., °C.	Magnetic Intensity, c.g.s. units			
	Alloy	Cementite	Iron Percarbide	Iron
20	209·2	134·8	128·7	217·6
240	192·5	19·8	58·7	208·8
290	186·4	9·0	18·4	205·8

* Values for cementite and iron percarbide are taken from Fig. 3

Table II; in addition, values measured for the annealed state are given to supplement Fig. 8.

As the sum of the fractions of ferrite and cementite present is $0{\cdot}927_6$, x (equal to $1 - (c + f)$) has the value of about $0{\cdot}072_4$. Thus n is approximately unity, and the low-temperature intensity for the unknown carbide must be of the same order as that for iron percarbide. Since the calculated amount of cementite will contain $0{\cdot}20_0\%$ of the total specimen mass as carbon, the unknown carbide must contain an amount of carbon equal to $0{\cdot}64\%$ of the specimen mass, if none is dissolved in the ferrite ; if its proportion is $0{\cdot}072_4$, this is equivalent to about $8{\cdot}8\%$ of carbon in the carbide. Iron percarbide contains about $8{\cdot}9\%$ of carbon by weight (the $Fe_{20}C_9$ composition).

Similar calculations for other specimens have given corresponding results for tempering temperatures near 300° C. The accuracy of the fit between the recalculated intensities and those actually measured, as shown in Table II, confirms that in this state the phases present have the properties assumed.

Attempts to analyse alloys tempered at above 300° C. have so far failed ; the recalculated intensities do not check with the measurements. It is probable that this is because of some change in the phase which resembles iron percarbide, for in the annealed state the analysis is again satisfactory.

DISCUSSION

Heidenreich, Sturkey, and Woods,[4, 5] and Jack,[6] have observed that the precipitate formed at the first tempering stage has a hexagonal crystal structure, in agreement with the present observation that it is not cementite. It probably belongs to the hexagonal ε-phase iron carbide which has been reported[20] ; because the phase is expected to have variable composition, the carbon content of the precipitate is uncertain. The results suggest that it contains more than $7{\cdot}7\%$ of carbon, for even after the main third tempering stage, there is evidence that a carbide is present which contains more carbon than this amount, probably $8{\cdot}8\%$; it would be hard to understand why a precipitate with lower carbon content should decay through one with more carbon to form another, cementite, again having a lower composition ($6{\cdot}68\%$ of carbon).

Figure 5 indicates that with this limitation on composition, the Curie point of the first-stage precipitate may be considerably lower than 400° C., and different from 380° C., the Curie point previously given for hexagonal Fe_2C ($9{\cdot}7\%$ of carbon). Thus the precipitate probably differs in composition from Fe_2C : if the ε-phase iron carbides are similar to the ε-phase iron nitrides, which do not extend beyond Fe_2N, it is likely that the phase has less and not more carbon than Fe_2C.

While the magnetic measurements show that the second carbide which is present after tempering to the end of the main third stage has properties very similar to those of iron percarbide, there is no evidence as to the crystal structure of the precipitate : indeed, it is not impossible for an iron carbide of the ε-phase also to have the same magnetic properties.

Lehrer[22] has shown that for ε-phase iron nitrides, increasing the nitrogen content to 7% causes the Curie point to rise ; further addition of solute causes a decrease, and it tends to the absolute zero of temperature as the phase limit Fe_2N is approached. Figure 10 is taken from Lehrer's paper. If a similar effect occurs in the ε-phase iron carbides, it is possible that some carbide belonging to this phase has a similar (σ, T) curve and composition to iron percarbide, while the Curie point of ε-Fe_2C is 380° C.

The electron diffraction work of Heidenreich, Sturkey, and Woods[4] suggests that even after tempering for half an hour at a temperature as high as 350° C., there is some hexagonal phase still present : the material that they used, however, was a steel of commercial purity, and an impurity element may have raised the temperature at which the main third stage occurred to above that for pure materials. Because of this, no great weight may be attached to this particular electron diffraction observation, in any attempt to establish the identity of the precipitate which has the same composition as iron percarbide.

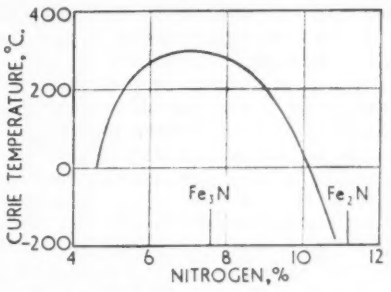

Fig. 10—The dependence of Curie temperature on composition for ε-phase iron nitrides (Lehrer[22])

Table II

COMPARISON OF CALCULATED AND MEASURED INTENSITIES

Temperature, °C.	Magnetic Intensity, c.g.s. units		
	Measured	Calculated	Measured for Annealed State
20*	209·2	209·2	208·6
50	207·8	207·8	207·2
75	206·6	206·6	205·9
100	205·3	205·3	204·3
125	203·7	203·8	202·4
150	201·9	202·1	200·3
170	200·4	200·5	198·2
190	198·6	198·8	195·7
200	197·5	197·7	194·2
210	196·4	196·6	192·4
220	195·2	195·3	190·3
230	193·9	193·9	188·4
240*	192·5	192·5	187·0
250	191·1	191·2	185·9
260	189·7	189·8	184·9
270	188·3	188·5	184·0
280	187·2	187·4	183·2
290*	186·4	186·4	182·5

* The equations were formed for these temperatures, at which the measured and calculated intensities are automatically equal

No other electron diffraction work showing the presence of the hexagonal structure in pure materials after this heat-treatment is known.

If the phase in question is iron percarbide, the changes observed at the third tempering stage may be attributed to the breakdown into $Fe_{20}C_9$ of the ε-phase iron carbide precipitated at the first stage; such a process is known to occur in the free state. Between 300° C. and 550° C., the iron percarbide would then react with free iron to form cementite; Hofer and Cohn[18] have stated that this reaction can be completed by heating slightly below 500° C. for a few hours, a reaction rate not very different from that observed in the steel.

Although there is no direct evidence to show that the carbide cannot belong to the ε-phase, the information available on the behaviour of ε-Fe_2C makes this appear improbable. In all known cases, ε-Fe_2C has formed iron percarbide on thermal decomposition; there is no reason to suppose that the first-stage precipitate in the steel, even if differing slightly in composition from Fe_2C, should not decompose in the same way.

Since this paper was written, additional support has been given to the view put forward by the authors that iron percarbide is present after the third tempering stage. Roberts[25] has detected X-ray diffraction lines of iron percarbide in the pattern from residues extracted electrolytically from plain carbon steels, tempered at above 250° C. Hofer and Cohn,[26] in a study of the tempering of a synthetic mixture of finely divided iron and ε-phase iron carbide, observed a process very similar to that suggested in the present paper.

Acknowledgments

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APPENDIX

Calculation of the Dependence of Curie Point on the Assumed Composition for the First-Stage Precipitate

If the form of the reduced (σ, T) graph of a material is known, and also the values of the magnetic intensities at two temperatures (T_1 and T_2 measured on the absolute scale), below the Curie point and preferably not close together, the Curie point (θ) may be estimated. Choice of a value for one reduced temperature T_1/θ fixes the other, because $T_1/T_2 = \dfrac{T_1/\theta}{T_2/\theta}$. To each value of reduced temperature there corresponds on the curve a reduced intensity σ/σ_0, where σ is the intensity at a temperature T, and σ_0 is that at the absolute zero. Choosing a value of T_1/θ which corresponds to reduced intensities which are in the same ratio as the actual intensities possessed by the material at the temperatures considered gives the Curie point (θ) directly, because T_1 is known. The solution is unique for a given reduced curve.

To obtain the magnetic intensities for the precipitate at the specified temperatures, it is necessary to know the amounts of the three phases, ferrite, retained austenite, and carbide precipitate, that are present, since the values obtained from measurements on the alloy depend on the individual products of specific intensity and mass. The proportion of precipitate can only be calculated if its carbon content is known, by accounting for the total amount of carbon in the alloy : in the calculation, therefore, the intensities at the required temperatures are obtained as a function of the assumed composition of the carbide.

If the effect of dissolved carbon on the saturation intensity of martensite is simply one of dilution, the fraction of retained austenite (A) is given by :

$$\sigma_Q = \sigma_{Fe}\left(\frac{100 - c}{100}\right)(1 - A),$$

where σ_Q is the measured intensity in the quenched state at the first temperature,
σ_{Fe} is the intensity of iron at the same temperature,
and c is the percentage of carbon in the steel.

After tempering high-carbon steel to the end of the first stage, Kurdjumov and Lyssak[2] found that about 0·3% of carbon remained dissolved in the ferrite, *i.e.* $(c - 0{\cdot}3)\%$ of carbon was precipitated.

Thus the intensity at the first temperature, after tempering to the end of the first stage, is equal to :

$$(1 - A)\left[\sigma_{Fe}\frac{(100 - 0{\cdot}3)}{100}\left\{1 - \frac{(c - 0{\cdot}3)}{h}\right\} + \sigma_p\frac{(c - 0{\cdot}3)}{h}\right]$$

where σ_p is the magnetic intensity of the precipitate at the temperature considered.
h is its carbon content expressed as a percentage,
and $\dfrac{(c - 0{\cdot}3)}{h}$ is the fraction of the total mass which is precipitate.

This equation was solved for σ_p at each of the required temperatures, after inserting a range of assumed values for the carbon content of the precipitate. The temperatures were chosen as far apart as possible, on a reversible part of the measured (σ, T) graph for the alloy, to increase the sensitivity of the Curie point estimation. A simple graphical technique was devised to determine by trial and error the values of best fit for the reduced temperatures and intensities. The reduced (σ, T) curve used was that obtained for iron percarbide : it was very similar to the curves obtained for cementite and some alloys in the ε-phases of the iron–nitrogen and iron–carbon–nitrogen systems.

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Calibration Furnaces for Total-Radiation Pyrometers

By E. J. Burton, B.A., and R. Mayorcas, B.Sc.

SYNOPSIS

The essential requirements of a furnace for calibrating total radiation pyrometers in the temperature range 1000–1750° C. are (*a*) that it emits radiation which is substantially that of a black body ; (*b*) that it provides a sufficiently large source (at least 3 in. dia. for existing industrial pyrometers) ; and (*c*) that the temperature of the furnace may be rapidly changed within the range of calibration.

An electrically heated graphite-tube furnace 36 in. long and 3 in. internal dia., which satisfied these conditions, has been constructed, but the large current (1400 amp.) required to heat the tube demanded a special transformer installation. A second furnace requiring only 150 amp. has been built. In this the resistance is increased by cutting the tube to form a grid.

The emissivity of the radiating source has been increased by grooving its surface. Alternatively, a bundle of thin-walled graphite tubes, each acting as a black body, has been used as the black radiator ; the length of furnace required at a uniform temperature is then reduced to the length of the tubes.

THE development of new techniques and the demand for greater thermal efficiency in the steel industry makes it necessary to measure high temperatures with consistent accuracy. In particular the roof temperature of the open-hearth furnace is critical for the determination of the rate of steel melting ; it has been shown[1] theoretically that during refining an increase of 10° C. increases the net heat transfer to the steel by about 10%. The majority of furnaces in this country have silica roofs, and although the roof will remain intact when the silica bricks begin to soften at 1660° C., long periods at 1680° C. will cause the roof to run and will seriously shorten its life. It is, therefore, necessary to ensure that the radiation pyrometer measuring the roof temperature can be relied upon to an accuracy of $\pm$ 1% in this temperature range under the unfavourable conditions of use. A standard radiator, preferably black, should be available so that the performance of any pyrometer can be tested under controlled conditions in the laboratory and so that the calibration of any pyrometer used in the works can be quickly and accurately checked.

CALIBRATION FURNACE DESIGN

The direct calibration of commercial total radiation pyrometers requires a source of black-body radiation sufficient to fill the largest aperture demanded by existing instruments. The source must therefore be

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Mr. Burton and Mr. Mayorcas are on the staff of the Physics Laboratories of the Association.

at least 3 in. in dia. Previously such large sources have been provided by electrically heating strips of nickel[2] or Nichrome, but this method suffers from the limitation that the temperature of the strip cannot be raised above 1300° C. in the case of nickel or above 1150° C. in the case of Nichrome. The method depends on the calibration of the radiator against a standard radiation pyrometer with the same spectral response characteristics as the first pyrometer, but with a small aperture so that it, in its turn, can be calibrated on a small truly black-body source. It was, therefore, decided that a 3-in. aperture calibration furnace which would quickly attain any temperature within the range 1000–1750° C. with the minimum power consumption, would be of value.

For the lowest possible power consumption the furnace tube should be as short as the desired blackness of the source will permit, and therefore the emissivity of the material for the inner face of the tube should be as high as possible. A gas-fired furnace for this temperature range would require preheated air, and the tube used as the source would have to be protected from the furnace gases by a covering of at least 0·5 cm. of alumina refractory. To compensate for the heat lost by conduction and radiation in this refractory, an inside furnace temperature of 1870° C. would be required to obtain a source temperature of 1600° C.

With electrical heating methods either a wire-wound refractory tube, a directly heated resistor tube, or a tube heated by high-frequency induction can be used. The nature of the winding and refractory make it essential to raise the temperature of a wire-wound furnace slowly. The latter two methods may both use a graphite tube to give an initially highly emissive surface, but of these the resistor-tube method is more convenient, since the induction method requires the purchase or construction of a high-frequency generator. Two types of resistor furnace were accordingly constructed.

High-Current Furnace

This furnace shown in Fig. 1 is an adaptation of a glass-melting furnace described by Fortey and Haines.[3] A graphite tube, 36 in. long with a 3-in. internal dia., is mounted as the central element of a cylindrical furnace and is surrounded by four concentric rings of graded insulation. The tube walls are $\frac{1}{4}$ in. thick except for the 12-in. central portion, where the thickness is increased to $\frac{3}{8}$ in. Thus more heat is liberated near the water-cooled ends, and the temperature over the central region is kept more uniform.

The current is introduced into the tube by brass water-cooled electrodes screwed on to each end. To improve the electrical contact between the brass and the graphite, the ends of the tube were turned to receive brass cones, which are pressed tightly on to the graphite by brass rings screwing into the electrode. The contact may be further improved by copper-plating the ends of the tube[4] and soldering the electrodes to them, but, since the voltage drop from electrode to graphite showed that only about 3% of the total power is spent in the inter-facial contact, it was decided that the small power saving would be off-set by the greater difficulty in changing the tube.

Nitrogen (free from oxygen and water vapour) is introduced into the furnace to reduce burning to a minimum. Despite this precaution, however, the tube slowly burns, especially in a ring about 5 in. from the water-cooled end, when the experiments require the furnace to be exposed to the atmosphere, as for example, when optical pyrometer readings are taken without any intervening screens. The life of a tube has been extended by inserting thin graphite sleeves to cover this danger area and a tube generally lasts for at least 70 hr.

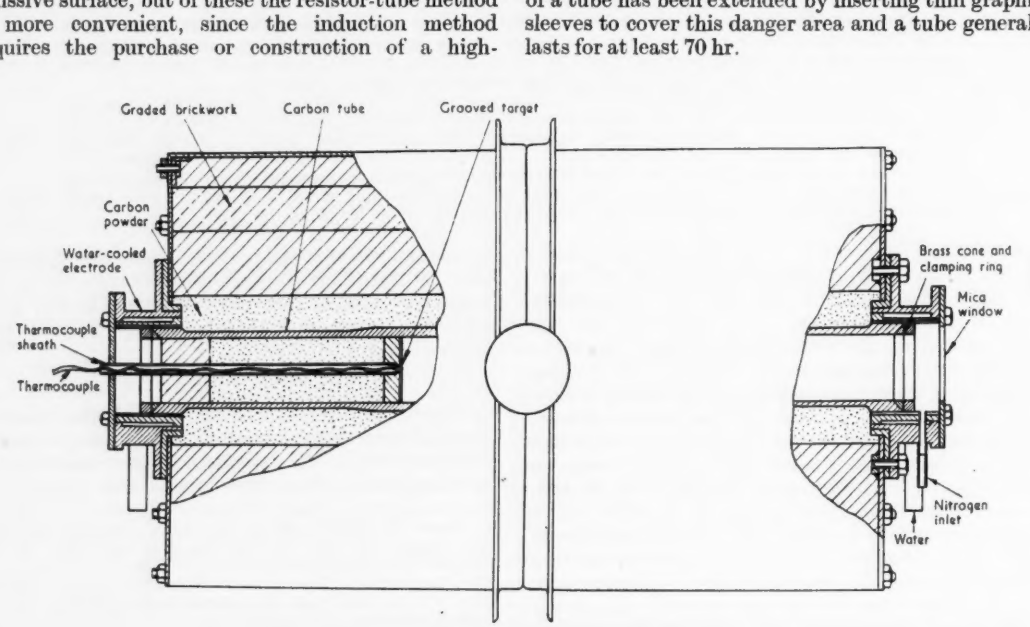

Fig. 1—3-in. carbon-tube furnace

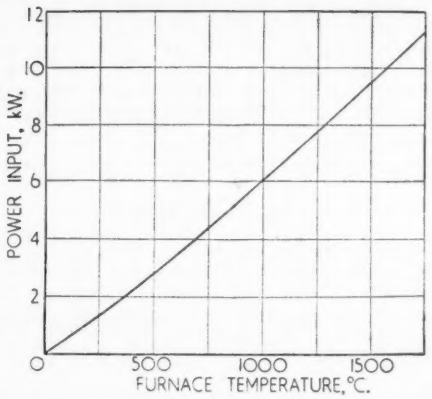

Fig. 2—Average power input across secondary terminals of transformer

The power consumption of the furnace measured across the secondary terminals of the transformer at different temperatures is shown in Fig. 2. About $\frac{5}{9}$ of the energy output is lost by conduction down the tube into the water-cooled end, and as the tube burns the temperature near the electrode rises and the power consumption increases. There is almost no limit to the speed with which the furnace may be brought to any desired temperature, provided sufficient current is available. With the present transformer, which has a maximum output of 1500 amp., the furnace will reach 1600° C. in about $1\frac{1}{2}$ hr.

Cut-Graphite-Tube Furnace

The heating element of this furnace consists of a 17-in. graphite tube with a 3-in. internal dia., cut as shown in Fig. 3. The resistance of this furnace is about 20 times that of the simple tube furnace. Each strip in the grid is kept separate from its neighbours by an alumina spacer. The electrodes, provided by an extension of two pairs of strips at the ends of a diameter of the tube, are widely separated and allow the grid to be suspended in a cylindrical metal box (*see* Fig. 4). The box is divided into two parts by a graphite sleeve, and the annular space between this and the metal casing is filled with carbon powder, which

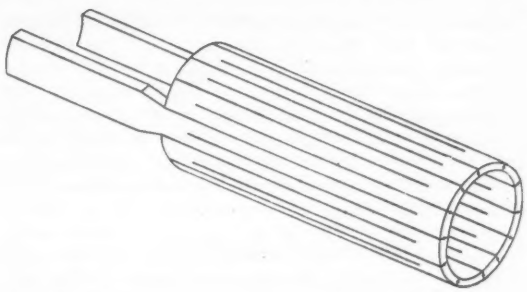

Fig. 3—Heating element of cut-graphite-tube furnace

serves as the main thermal insulation. The space between the graphite sleeve and the cut tube is filled with alumina powder, which insulates the tube thermally and electrically insulates the strips from each other.

The current is introduced into the tube either by copper clamps tightened about the copper-sprayed electrodes or by flexible copper leads tamped into the graphite. The copper electrodes, which are not water-cooled, reach a temperature of about 150° C. Thus the power lost by conduction to the electrodes is greatly reduced compared with that lost in the simple tube furnace. This furnace requires about 3 kW. to maintain it at 1600° C., and the current consumption depends on the number of strips in the grid. With the present arrangement of 12 pairs it requires about 150 amp. Generally, this current can be conveniently supplied by a welding transformer.

The tube is heated in an atmosphere of nitrogen, since, because of its structure, its resistance is quickly affected by burning. Also, since there is no steep temperature gradient along the strips, the sighting end of the tube reaches a temperature of about 1400° C. when the source is at 1620° C., and any air leaking into the furnace reacts with the high-temperature carbon in this zone. A graphite sleeve is therefore inserted as far as possible into the tube and is held just clear of the grid by the refractory ring at the mouth of the tube. This sleeve reaches a high

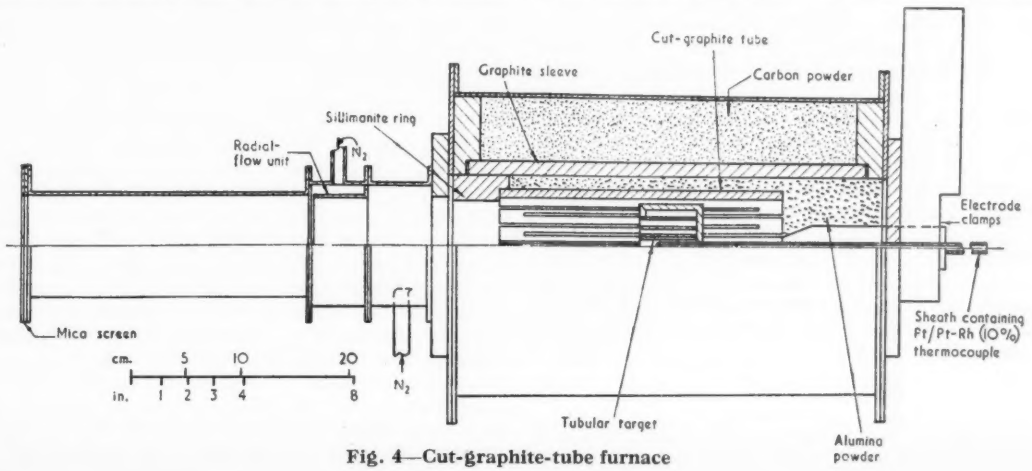

Fig. 4—Cut-graphite-tube furnace

temperature by radiation and reacts with the oxygen in any air that leaks into the furnace. The furnace is usually protected from infiltrating air by a mica window, which tends to become lightly covered with a sublimate, distilled from the binding material in the graphite. Therefore, this screen is swung aside for pyrometer readings, and a stream of nitrogen is blown radially across the tube to prevent the re-entry of air into the furnace.

FURNACE EMISSIVITY

Considerable attention has been given to the geometrical design of the emitter, to obtain the maximum emissivity. So far, two radiating shapes have been used, namely the grooved graphite disc and the tubular target.

Grooved Graphite Disc

This target is made from a $\frac{1}{2}$-in. thick graphite disc of the same diameter as the tube. The face of the disc is ruled with grooves having a vertical angle of 30°. This produces a series of wedge-shaped cavities and so increases the surface emissivity.[5] If the total emissivity of the graphite is taken to be 0·64*,[6] the grooving has been calculated[7] to increase its value to 0·82.

The emissivity of the disc (radius r) surrounded by a uniform temperature zone of length $4r$ has been computed[8] to be 0·985 with no grooving, and 0·995 with grooving. The grooving of the target not only increases the effective emissivity of the base but also greatly decreases the dependence of the emitted radiation on the temperature of the surrounding walls. For example, assuming that 90% of the reflected radiation originates from the side walls if the target is at 1600° C. and the surrounding walls reach 1620° C., the apparent emissivity, *i.e.*, the ratio of the total radiation from the target to the total radiation emitted by a black body at 1600° C., will be increased to 0·998 with no grooving, and to 0·999 for a grooved target. The radiation is thus increased by 1·3% with no grooving, and by 0·4% with grooving. This type of source has been used only with the high-current furnace. The validity of the assumption that there was a uniform temperature enclosure with a length to diameter ratio of 2 : 1 was confirmed by measuring the temperature along the cylindrical walls. This was achieved by placing along the tube graphite shells which, together with the part of the tube that they covered, formed a cone with a base somewhat greater than half its length of $\frac{1}{2}$ in. The shells, with a wall thickness of $\frac{1}{16}$ in., had a negligible thermal capacity and could, therefore, be kept at the same temperature as the adjacent walls by conduction and radiation. Thus, the opening of the cone provided a source of black-body radiation at the temperature of a small area of the furnace, and it was possible to measure this temperature with a disappearing-filament pyrometer designed by Barber.[9] Results obtained during typical running conditions with no diaphragms in the furnace are as follows :

Observer	Target	Wall	1st Shell	2nd Shell	3rd Shell	4th Shell	Time
EJB	1552	1558	*	1532	1472	1389	15·50
RM	1549	1555	*	1530	—	—	16·00
ELK	1550	—	*	1529	1468	1378	16·20
EJB	1558	—	1562	1533	1483	1405	17·03
Distance from Target, in.	0	Approx. 1	4½	9½	13	16½	

* Shell was indistinguishable
— Reading was not taken

The shell nearest the target could only once be distinguished, thus illustrating the uniformity of temperature in this zone. Although the above calculation has shown that this temperature gradient is satisfactory, it is considered that it could be further improved by experimenting with the tube shape.

Tubular Target

The second form of target consists of a bundle of graphite tubes closely backed by a thin disc of graphite, and the whole target is insulated with carbon powder and insulating brick. Each tube lies parallel to the main tube and has a length to diameter ratio of 6 : 1, radiating as a source having an emissivity differing from unity by only three parts in ten thousand. The interstices between the tubes will radiate with an emissivity even higher than this. But the edges of the tube walls, which were chamfered, have an emissivity of between 0·64 and 0·90. Therefore the blackness of this form of target is limited only by the excellence of the machining of the tubes and by the uniformity of the temperature they reach. This type of target has been used successfully on both types of furnace. At a steady state, the tubes often cannot be distinguished by the naked eye, although they can be seen through a blue glass.

Although the temperature variation may only be about one or two degrees, the use of visual observations to establish the blackness of a graphite uniform temperature enclosure may be deceptive. The spectral emissivity of polished graphite in the visible range is 0·87 whereas the total emissivity at 1600° C. is only 0·64. The furnace will, therefore, always be blacker in the visible than in the infra-red range.

A simplified version of this target, consisting of a short cylinder of graphite, honeycombed with holes, has been used for less accurate work with the cut-graphite-tube furnace since it is easier to insert into that type of tube.

CALIBRATION OF PYROMETERS

The pyrometer to be calibrated is clamped coaxially with the graphite tube. Two or three graphite diaphragms are placed along the tube to limit the radiation to that required by the optics of the pyrometer.[10] A water-cooled blackened diaphragm between the pyrometer and the furnace also reduces the stray radiation reaching the pyrometer. The temperature of the body of the pyrometer is kept approximately constant during the calibration by running water through a surrounding water-cooled jacket. The furnace is brought quickly to about the required temperature, and then the current is reduced and is kept constant until the furnace reaches a steady state. Generally the furnace tends to drift 2° or

* This value is for polished graphite and Michaud has shown (private communication) that the emissivity increases to 0·90 if the surface is slightly burnt.

3° every 5 min. and the direction of drift is, therefore, periodically changed. Readings are taken at approx. 3-min. intervals ; the average of three or four such furnace temperature readings is then taken as the correct temperature corresponding to the given pyrometer reading. The spread of furnace temperatures taken in this way does not generally exceed 2 or 3°.

The furnace temperature is measured with a sheathed platinum/platinum–rhodium thermocouple,[11] which in the case of the grooved target lies in the plane of the grooving, and in the tubular target lies between the tubes and parallel to them. The reading of the thermocouple is checked whenever possible against a disappearing-filament pyrometer, particularly when the furnace temperature exceeds 1500° C.

CONCLUSIONS

The method of using resistor-type furnaces gives a sufficiently black source, the temperature of which can be quickly varied between 1000° and 1750° C. The high-current furnace has proved a useful calibration tool in the laboratory but the cut-tube furnace is more suitable for use in steelworks because its power supply may be obtained from a welding transformer. The use of a bundle of tubes as a black-body source enables the length (measured in tube diameters) of the furnace required at a uniform temperature, to be considerably reduced.

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The Effect of Tension on Torque and Roll Force in Cold Strip Rolling

By W. C. F. Hessenberg, M.A., F.I.M., and R. B. Sims, B.Sc., A.M.I.Mech.E.

SYNOPSIS

The rolling of mild-steel strip with front and back tension has been studied on the B.I.S.R.A. experimental rolling mill, to determine the effect of tension on the roll force and torque and, if possible, to suggest quantitative relationships between these variables.

Simple approximate formulae for calculating the effect of tension on roll force and torque are proposed, and comparison is made between calculated and experimental results. The difficulties inherent in more elaborate methods of calculation are discussed.

The energy of rolling is composed of the energy required to deform the strip and the energy absorbed in overcoming friction between the strip and the rolls. Since the former depends only on the properties of the strip and the amount by which it is deformed, any effect of tension on the energy of rolling must arise from changes in the frictional component. In most cases this component is relatively small, and the experimental results confirm that the total energy of rolling is, for all practical purposes, unaffected by the application of tension.

Introduction

In the cold rolling of strip it is common practice to apply tension to the strip as it enters and leaves the rolls. The effects of tension are known in a general way from practical experience and from the indications of various theories of the rolling process. The effect of back tension is to increase the torque that must be applied to the work rolls ; front tension has the opposite effect. Both back and front tension reduce the separating force between the rolls, and hence reduce the load on the bearings and the housings. The aim of the experiments described in this paper

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Mr. Hessenberg is Head of the Mechanical Working Division of the Research Association and Mr. Sims is Head of the Rolling Section of the Mechanical Working Division.

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has been to measure these effects precisely and to indicate, where possible, quantitative relationships of practical value.

Laboratory experiments have previously been carried out by Lueg[1, 2] and his collaborators at the *Kaiser-Wilhelm-Institut für Eisenforschung*. These were made on a very small mill of unusual design. The work rolls were only 10 mm. dia. × 80 mm. long, and each roll was backed up by five support rolls arranged in two tiers. In particular, the ratio of the roll radius to the initial strip thickness, a factor which plays an important part in the mechanics of rolling, was of the order of 10 : 1, whereas in practice it is more usually about 100 : 1. To date, however, theirs appear to be the only published experiments on tension which include measurement of both roll force and torque.

Notation

The following symbols are used :

R = radius of the undeformed roll, in.
h = thickness of strip at any point, in.
h_1 = entry thickness of the strip in the pass, in.
h_2 = exit thickness of the strip in the pass, in.
δ = $h_1 - h_2$, the draft in the pass, in.
r = reduction in the pass = δ/h_1 (written fractionally or as a percentage)
r_1 = total reduction from the annealed condition before the pass
r_2 = total reduction from the annealed condition after the pass
α = angle of contact, radians
μ = coefficient of friction
E = energy of deformation
t_f = front tension stress, tons/sq. in.
t_b = back tension stress, tons/sq. in.
T_f = front tension force, tons per inch width of strip
T_b = back tension force, tons per inch width of strip
T = $T_f - T_b$
P = roll force, tons per inch width of strip
G = torque per spindle, tons-in. per inch width of strip
ϕ_n = angular co-ordinate at the neutral plane
f = forward slip (expressed fractionally)
d = distance between identical roll marks on rolled strip.

The deformation of the strip between the rolls will be considered as plane compression, so that the spread is negligible. At any point on the arc of contact between the rolls and strip, in any section transverse to the roll axis, let :

s = normal roll pressure, tons/sq. in.
p = vertical roll pressure, tons/sq. in.
R' = radius of curvature of the deformed roll, assumed constant and given by Hitchcock's equation, in.
θ = angular co-ordinate, radians. ($\theta = 0$ at the point of exit, and $\theta = \alpha$ at the point of entrance)
k = yield stress in plane compression, tons/sq. in.

The suffixes used are as follows :

$_0$ denotes the quantity obtained when no tensions are applied to the strip
$_{1, 2}$ refer to quantities at the point of entry and exit, respectively.

EXPERIMENTAL DETAILS

The present experiments were carried out on the B.I.S.R.A. 10 in. × 10 in. 2-high cold strip mill, which has been fully described elsewhere.[3] Two thicknesses of strip were rolled, giving roll radius/initial strip thickness ratios of approximately 80 : 1 and 130 : 1. The rolls were of 102 Shore hardness, ground plane parallel with an axial roughness of 15 ± 6 μ-in. The speed of rolling was 40 ft./min., and the lubrication was a copious flood of 10% soluble oil in water.

The strips were of commercial quality rimming steel with the analysis : 0·08% of C, 0·010% of Si, 0·030% of P, and 0·35% of Mn. They were initially in the form of coils 200 ft. long, $0{\cdot}063 \pm 0{\cdot}001$ in. thick, and $3{\cdot}50 \pm 0{\cdot}02$ in. wide. Some of the strips were cold rolled to approximately 0·038 in. thick in a single pass of 40% reduction, before the experiments were carried out. The yield stress of the annealed material in plane compression was obtained by the method described by Ford,[4] and the results are shown in Table I.

Measurement of the thickness of the strip was made over 10-in. gauge lengths marked on it at intervals of 20 ft. As each gauge length passed through the rolls, simultaneous measurements were made of the roll force, torque, and tensions, using the electric resistance strain gauge methods described by Rankine, Bailey, and Stanton.[5] Between each gauge length the tensions and reduction were adjusted as closely as possible to the desired nominal values. The torque and tension meters were calibrated by a dead-weight method, and the roll-force meter was calibrated in a universal testing machine.

Forward slip was determined by a method similar to that used by Puppe.[6] A fine line was scribed on the rolls parallel to the roll axis, and the imprint of the line was left on the strip. The distance between successive imprints enabled the forward slip to be determined from the formula :

$$f = \frac{d}{2\pi R} - 1 \qquad \text{.....(1)}$$

An estimate of the experimental errors was made during the rolling-down of annealed strip to 0·038 in. These experiments were carried out without tension and without any deliberate alteration to the conditions of the experiment. Using statistical methods it was possible to estimate, from the scatter of the measurements, the most probable value of roll force and torque at 40·00% reduction, and also the ' confidence limits ' within which 95% of the values may be expected to lie. The figures obtained were :

	Most Probable Value at 40·00% Reduction	95% Confidence Limits
Roll force, tons per inch width	16·56	±0·50
Torque, tons-in. per inch width	2·37	±0·06

There are indications that the limits vary slightly with the reduction, but the order of magnitude is the same.

EXPERIMENTAL RESULTS

The principal experimental results comprise measurements of roll force and torque at reductions of approximately* 30% and 50%, carried out on annealed

* As there are always sources of variability in the rolling process (such as variations in the hardness and shape of the ingoing strip, in its surface quality, and in the behaviour of the lubricant) which cannot be brought under full control, there was a certain amount of scatter in the values of the independent variables. Their measurement, however, was precise.

Table I

YIELD STRESS IN PLANE COMPRESSION

Figures are given in tons/sq. in.

Coil	Reduction, %								
	0	10	20	30	40	50	60	70	80
1	11·5	28·4	35·7	40·8	44·4	47·1	48·6	49·4	49·9
2	11·9	29·0	36·0	39·8	42·7	45·0	47·1	48·7	50·2
3	13·5	30·3	38·2	42·5	45·3	47·2	48·3	48·8	49·2
4	12·2	31·2	37·3	41·7	44·5	46·7	48·1	49·2	50·1
5	11·0	30·0	36·8	40·7	43·6	45·0	47·8	49·1	50·1
6	13·5	30·3	36·8	41·1	44·0	46·2	47·8	48·8	49·7

material and on material which had previously been cold rolled to a reduction of about 40%. Results are also included for the annealed strip during cold rolling in preparation for the latter experiments ; no tensions were applied in this case. The results, together with the measured values of the percentage reduction in thickness, applied tensions, forward slip, and energy per unit volume* calculated from the equation :

$$E = \frac{2G}{(1+f)Rh_2} + t_f - t_b, \quad \text{.....(2)}$$

are given in Table II.

Energy and Torque

Figure 1 and Table II show that the values of energy per unit volume are fairly constant within each group of nominal reductions, despite a wide range of applied tensions. If it could be assumed that the energy is not affected by the tensions, a very simple formula for the effect of tension on the torque could be derived, as follows :

The energy per unit volume at a given reduction is given approximately by :

$$E = \frac{2G}{Rh_2} + t_f - t_b.$$

Similarly,

$$E_0 = \frac{2G_0}{Rh_2}.$$

If $E = E_0$, then :

$$G = G_0 + \frac{Rh_2}{2}(t_b - t_f) \quad \text{.....(3)}$$

This equation has already been put forward by Hill,[7] who derived it from certain assumptions as to the effect of tension on the distribution of pressure over the area of contact between the rolls and the strip, and showed its equivalence with the assumption of constant energy when rolling with tensions.

Equation (3) has been tested against the experimentally measured torques. The calculated values are shown in column 5 of Table II, and the experimental values in column 4. The required values of G_0 were obtained from an experimentally determined curve of torque plotted against reduction, shown in Fig. 2. The difference between the experimental and calculated results is shown in column 6.

Whilst the comparison of calculated and experimental results is the real test of the usefulness of equation (3), it is interesting to examine the extent to which the assumption that tension does not affect the energy is valid. The scatter in the energy results must be analysed to determine how much, if any, is due to the application of tension. The method used is statistical, and is based on the assumption that within a restricted group of experimental results the effects of the independent variables on the dependent variable are linear. This amounts to solving the equation :

$$E = \bar{E} + A(r - \bar{r}) + B(t - \bar{t}) \quad \text{.....(4)}$$

where $t = t_f + t_b$; $\bar{E}$, $\bar{r}$, and $\bar{t}$ are the mean values of E, r, and t for the group of results under consideration ; and A and B are coefficients. The assumption of linearity may not be strictly true, but the analysis

* The figures shown in Table II are in units of horsepower-hours per ton, which is a measure of energy per unit weight. The energy per unit volume may be obtained from these figures by means of a simple conversion factor, which is constant over the entire range of experiments.

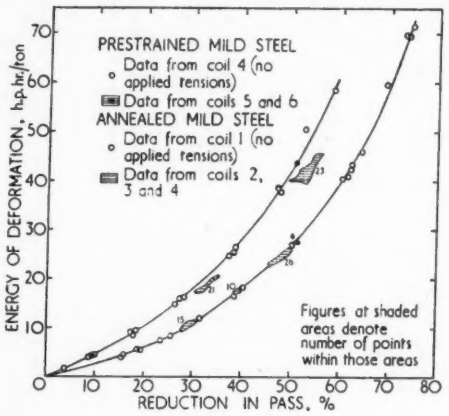
PRESTRAINED MILD STEEL
Data from coil 4 (no applied tensions)
Data from coils 5 and 6
ANNEALED MILD STEEL
Data from coil 1 (no applied tensions)
Data from coils 2, 3 and 4
Figures at shaded areas denote number of points within those areas
ENERGY OF DEFORMATION, h.p.hr./ton
REDUCTION IN PASS, %

Fig. 1—Relation between energy of deformation and reduction in pass

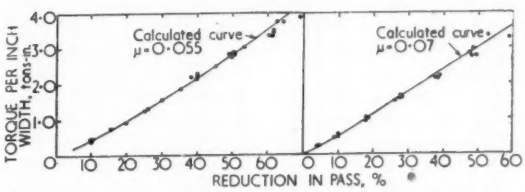

Fig. 2—Experimental values of torque plotted against reduction in pass

Table II

RESULTS FOR ANNEALED MILD STEEL
Initial Thickness: 0·063 in.

1	2	3	4	5	6	7	8	9	10	11
Reduction in Pass, %	Drag Tension Stress, tons/sq. in.	Wind Tension Stress, tons/sq. in.	Experimental Net Torque per Spindle per Unit Width, tons-in.	Calculated Net Torque per Spindle per Unit Width, tons-in.	$G_{exp} - G_{calc}$	Experimental Roll Force per Unit Width, tons	Calculated Roll Force per Unit Width, tons	$P_{exp} - P_{calc}$	Total Energy, h.p.hr./ton	Forward Slip, %
r	t_b	t_f	G_{exp}	G_{calc}		P_{exp}	P_{calc}		E	f
Coil 2. Nominal Reduction 30%										
29·3	0	1·8	1·39	1·37	0·02	13·5	13·3	0·2	10·3	1·47
29·4	0	10·2	0·47	0·40	0·07	12·6	11·6	1·0	10·5	5·69
30·0	0	11·2	0·40	0·36	0·04	12·2	11·6	0·6	10·9	6·78
30·4	0	16·1	−0·13	−0·16	0·03	11·6	10·8	0·8	11·2	11·25
29·9	0	19·8	−0·65	−0·64	−0·01	10·6	10·0	0·6	11·1	15·82
30·2	2·7	0	1·99	1·92	0·07	13·2	13·3	−0·1	11·2	0·26
29·0	2·8	0	1·96	1·87	0·09	12·9	13·0	−0·1	10·7	0·29
30·0	2·8	0	1·90	1·93	−0·03	13·1	13·3	−0·2	11·1	0·29
29·5	2·8	7·6	1·15	1·04	0·11	12·0	11·6	0·4	11·1	1·79
29·3	3·0	10·8	0·70	0·69	0·01	11·5	11·0	0·5	10·2	4·19
29·1	3·1	11·5	0·69	0·71	−0·02	11·5	10·8	0·7	10·7	4·25
29·9	3·1	15·9	0·25	0·16	0·09	10·8	10·1	0·7	11·1	7·48
30·0	3·1	20·0	..	..	..	9·9	9·3	0·6	..	11·41
30·8	6·2	0	2·40	2·36	0·04	11·8	12·8	−1·0	11·6	−0·13
31·1	6·3	0	2·46	2·38	0·08	11·9	12·9	−1·0	11·9	−0·13
31·3	6·4	0	2·41	2·40	0·01	11·8	12·9	−1·1	11·5	−0·19
29·5	6·2	1·8	2·11	2·08	0·03	11·6	12·2	−0·6	10·6	−0·13
29·4	6·3	6·0	1·67	1·60	0·07	11·3	11·2	0·1	10·7	0·54
28·7	6·2	9·6	1·18	1·14	0·04	10·7	10·5	0·2	10·2	1·53
28·7	6·5	10·6	1·12	1·06	0·06	10·6	10·2	0·4	10·2	1·82
29·5	6·3	11·5	1·08	0·99	0·09	10·4	10·2	0·2	10·9	1·79
27·8	6·4	12·3	0·86	0·82	0·04	10·1	9·7	0·4	9·8	2·65
29·3	6·2	15·4	0·62	0·52	0·10	9·7	9·4	0·3	10·8	4·25
28·7	6·2	19·2	1·14	1·05	0·09	9·1	8·6	0·5	10·5	7·45
28·4	6·7	20·1	0·08	−0·02	0·10	9·1	8·2	0·9	10·5	7·45
Coil 3. Nominal Reduction 50%										
48·2	0	3·8	2·45	2·48	−0·03	17·6	16·8	0·8	24·8	1·05
48·2	0	7·7	2·15	2·16	−0·01	17·1	15·9	1·2	25·0	1·98
46·6	0	9·2	1·96	1·91	0·05	16·9	15·4	1·5	23·8	2·72
47·2	0	11·2	1·75	1·79	−0·04	16·5	15·2	1·3	23·6	3·52
46·8	0	14·8	1·43	1·46	−0·03	15·9	14·2	1·7	23·1	5·62
46·2	0	18·3	1·15	1·12	0·03	15·3	13·4	1·9	23·0	8·69
50·1	2·9	0	3·08	3·15	−0·07	16·4	17·3	−0·9	26·9	−0·19
48·3	3·1	0	3·04	3·05	−0·01	17·0	17·0	0	25·5	0·19
49·4	3·1	3·7	2·76	2·84	−0·08	16·4	16·2	0·2	26·2	0·26
48·7	3·1	7·9	2·40	2·43	−0·03	15·8	15·3	0·5	25·2	1·37
45·7	3·1	8·9	2·20	2·14	0·06	15·9	14·7	1·2	23·4	1·85
47·9	3·1	11·4	2·07	2·09	−0·02	15·4	14·5	0·9	24·5	2·30
47·5	2·9	15·2	1·73	1·72	0·01	14·8	13·6	1·2	24·0	3·96
45·7	3·1	17·8	1·43	1·46	−0·03	14·3	12·6	1·7	22·7	5·88
51·0	6·0	0	3·39	3·45	−0·06	15·6	17·0	−1·4	27·4	−0·19
50·1	6·3	0	3·37	3·43	−0·06	16·0	16·6	−0·6	26·4	−0·06
49·9	6·2	4·2	3·00	3·06	−0·06	15·4	15·6	−0·2	26·2	0·10
49·7	6·2	7·8	2·72	2·76	−0·04	15·0	14·5	0·5	25·9	0·45
48·2	6·3	9·9	2·46	2·49	−0·03	15·0	14·2	0·8	24·3	1·15
49·3	6·6	11·9	2·42	2·43	−0·01	14·5	13·8	0·7	25·8	1·25
48·2	6·2	15·6	2·04	2·00	0·04	14·3	12·7	1·6	24·7	2·68
49·1	6·2	19·4	1·75	1·74	0·01	13·8	12·2	1·6	25·0	4·47
51·3	9·1	0	3·65	3·71	−0·06	14·6	16·2	−1·6	27·8	−0·16
51·1	9·4	0	3·59	3·72	0·13	14·3	16·0	−1·7	27·1	−0·16
50·8	9·3	4·3	3·32	3·40	−0·08	14·5	15·2	−0·7	27·4	0·13
49·5	9·3	7·8	2·99	2·99	0	14·0	14·0	0	26·1	0·38
48·4	9·4	9·9	2·72	2·76	−0·04	13·7	13·4	0·3	24·7	0·70
50·2	9·1	12·5	2·62	2·66	−0·04	13·5	13·1	0·4	26·4	0·96
49·1	9·4	15·5	2·34	2·33	0·01	13·0	12·2	0·8	25·6	1·63
49·4	9·3	19·9	1·98	1·99	−0·01	12·5	11·2	1·3	25·4	3·13
Coil 4. Nominal Reduction 40%										
38·9	0	0	2·27	..	..	16·4	..	..	17·1	0·22
38·6	0	0	2·26	..	..	16·4	..	..	16·9	0·22
39·5	0	0	2·28	..	..	16·3	..	..	17·2	0·26
38·9	0	0	2·26	..	..	16·3	..	..	17·0	0·22
38·6	0	0	2·27	..	..	16·7	..	..	17·0	0·10
38·8	0	0	2·29	..	..	16·5	..	..	17·3	0
39·4	0	0	2·24	..	..	16·5	..	..	17·2	0·03
38·6	0	0	2·21	..	..	16·5	..	..	16·8	0·16
39·0	0	0	2·23	..	..	16·9	..	..	17·1	0·26
38·6	0	0	2·24	..	..	16·7	..	..	17·0	0·32
38·7	0	0	2·27	..	..	16·7	..	..	17·3	0·26
39·2	0	0	2·31	..	..	16·7	..	..	17·6	0
39·5	0	0	2·32	..	..	16·7	..	..	17·7	−0·03
39·1	0	0	2·32	..	..	16·8	..	..	17·7	0·03
38·9	0	0	2·32	..	..	16·9	..	..	17·4	0·19
38·7	0	0	2·32	..	..	16·9	..	..	17·4	0·19
39·1	0	0	2·31	..	..	17·0	..	..	17·8	0·10
39·6	0	0	2·41	..	..	17·1	..	..	18·1	−0·10
39·9	0	0	2·38	..	..	17·0	..	..	17·9	−0·06

Table II—*continued*

RESULTS FOR PRESTRAINED MILD STEEL
Initial Thickness : 0·0383 in.

1	2	3	4	5	6	7	8	9	10	11
Reduction in Pass, %	Drag Tension Stress, tons/sq. in.	Wind Tension Stress, tons/sq. in.	Experimental Net Torque per Spindle per Unit Width, tons-in.	Calculated Net Torque per Spindle per Unit Width, tons-in.	$G_{exp} - G_{calc}$	Experimental Roll Force per Unit Width, tons	Calculated Roll Force per Unit Width, tons	$P_{exp} - P_{calc}$	Total Energy, h.p.hr./ton	Forward Slip, %
r	t_b	t_f	G_{exp}	G_{calc}		P_{exp}	P_{calc}		E	f
Coil 5. Nominal Reduction 30%										
30·5	0	5·5	1·25	1·25	0	16·8	17·4	−0·6	17·4	5·78
30·9	0	10·4	0·87	0·97	−0·1	15·8	16·2	−0·4	17·1	7·86
32·2	0	11·9	0·90	0·95	−0·05	15·8	16·4	−0·6	18·4	8·92
33·0	0	16·4	0·63	0·74	−0·11	15·0	15·0	−0·7	18·8	12·21
34·0	0	20·8	0·40	0·53	−0·13	14·1	15·0	−0·9	19·6	15·82
31·3	5·8	0	1·99	2·04	−0·05	16·5	17·5	−1·0	17·8	2·21
31·5	5·8	0	2·00	2·05	−0·05	16·4	17·6	−1·2	17·9	2·49
32·5	5·7	3·8	1·77	1·75	0·02	16·0	16·9	−0·9	18·1	3·13
31·8	5·7	7·4	1·48	1·59	−0·11	15·3	16·2	−0·9	17·3	4·40
32·6	5·6	10·2	1·30	1·45	−0·15	14·8	15·8	−1·0	17·6	5·02
31·5	5·8	11·8	1·20	1·28	−0·08	14·5	15·0	−0·5	17·3	6·65
32·8	5·8	15·7	1·00	1·13	−0·13	14·0	14·5	−0·5	18·0	8·63
33·2	5·9	20·4	0·73	0·87	−0·14	13·0	13·6	−0·6	18·5	11·38
34·8	11·7	0	2·42	2·62	−0·20	14·0	17·2	−3·2	20·3	0·10
35·4	11·9	0	2·48	2·65	−0·17	13·9	17·3	−3·4	20·7	−0·10
34·5	11·3	4·2	2·12	2·32	−0·20	13·5	16·3	−2·8	19·8	0·48
33·9	11·7	8·2	1·90	2·06	−0·16	12·9	15·2	−2·3	19·7	1·18
32·8	11·9	10·5	1·69	1·67	0·02	12·6	14·4	−1·8	18·3	1·89
32·7	11·6	12·2	1·52	1·72	−0·20	12·3	14·1	−1·8	17·8	2·52
31·8	11·8	16·6	1·26	1·37	−0·11	11·8	13·1	−1·3	17·7	3·87
31·8	11·7	20·1	1·01	1·16	−0·15	10·9	12·2	−1·3	17·3	5·88
Coil 6. Nominal Reduction 50%										
52·1	0	4·2	2·53	2·49	0·04	22·8	22·4	0·4	41·5	6·3
52·8	0	8·6	2·36	2·35	0·01	21·8	21·5	0·3	42·2	8·09
51·5	0	10·1	2·23	2·17	0·06	21·4	20·6	0·8	40·0	8·82
53·5	0	12·9	2·19	2·20	−0·01	20·9	20·4	0·5	42·7	9·62
52·9	0	17·3	1·99	1·96	0·03	20·3	19·2	1·1	42·1	13·07
52·9	0	20·0	1·83	1·84	−0·01	19·5	18·7	0·8	40·9	15·08
51·0	5·9	0	2·93	2·90	0·03	21·0	21·5	−0·5	40·9	2·59
54·6	6·7	0	2·98	3·12	−0·04	20·7	22·5	−1·8	45·4	1·09
52·0	6·5	4·2	2·82	2·79	0·03	20·4	20·7	−0·3	42·7	2·36
52·7	6·4	8·6	2·53	2·63	−0·10	19·4	19·8	−0·4	42·2	4·03
54·3	6·5	10·9	2·47	2·62	−0·13	18·7	19·5	−0·8	43·5	3·48
53·1	6·6	12·5	2·43	2·48	−0·05	18·7	18·9	−0·2	42·8	5·02
53·5	6·4	17·2	2·20	2·28	−0·08	18·0	17·8	0·2	42·1	7·22
54·9	6·5	22·5	2·00	2·16	−0·16	16·8	16·8	0	44·1	8·63
54·5	12·3	0	3·07	3·36	−0·29	18·2	21·0	−2·8	42·3	0·35
56·4	12·3	0	3·11	3·44	−0·33	17·9	21·5	−3·6	45·6	0·26
55·1	12·4	3·9	2·91	3·22	−0·31	17·3	20·0	−2·7	43·9	0·58
54·6	12·1	8·9	2·71	2·97	−0·26	16·6	18·6	−2·0	43·4	1·02
54·3	12·4	11·1	2·52	2·87	−0·35	16·3	18·0	−1·7	41·6	1·25
54·3	12·3	13·3	2·52	2·77	−0·25	16·3	17·4	−1·1	43·0	1·76
53·3	12·3	17·5	2·31	2·52	−0·21	15·4	16·4	−1·0	41·9	2·27
53·0	11·9	21·1	2·07	2·32	−0·25	14·8	15·2	−0·4	39·7	3·93

is capable of yielding useful information, provided that the departure is not great and the range of the dependent variable is small. The solutions of equation (4) are as follows :

Annealed Strip

30% reduction : $E = 10·80 + 0·541(r - 29·55)$
40% ,, $E = 17·31 + 0·674(r - 39·00)$
50% ,, $E = 25·26 + 0·861(r - 48·74) - 0·026(t - 13·91)$...(5)

Prestrained Strip

30% reduction : $E = 18·36 + 0·813(r - 32·65) - 0·033(t - 15·87)$
50% ,, $E = 42·48 + 1·03(r - 53·52) - 0·076(t - 17·01)$.

The tension coefficient does not appear in the first two equations because, for the 30% reduction, it is too small to be statistically significant,* and because for the 40% reduction no tensions were applied in this group of experiments. The increasing coefficient of r reflects the course of the energy/reduction curves in Fig. 1.

In these experiments the ratio of the length of the arc of contact to the entry thickness of the strip is large, and it is justifiable to assume that the deformation of the strip is homogeneous.[8] In this case :

$$E = E_k + E_\mu \quad \text{.....(6)}$$

where E_k is the energy of homogeneous plastic deformation, and E_μ is the energy absorbed by friction between the rolls and the strip. Now E_k cannot be affected by the applied tensions, because it depends only on the properties of the material and its dimensions at entry and exit. The tension coefficients therefore mark the effect of tension on the frictional energy, and they increase numerically as the proportion of frictional energy to total energy increases, as is shown in Table III.

Roll Force

The roll force depends on the distribution of

* At the 0·05 level.

Table III

INCREASE OF TENSION COEFFICIENT WITH ENERGY RATIO

	E_μ/E^*	Coefficient of Tension
Annealed Strip		
30% reduction	0·190	Not significant
50% ,,	0·225	0·026
Prestrained Strip		
30% reduction	0·263	0·033
50% ,,	0·392	0·076

* Determined experimentally

pressure over the arc of contact, and any detailed theory of the effects of tension on roll force must take into consideration the effect of tension on the pressure distribution. This is done in Orowan's[9] general theory and in Bland and Ford's[10] method of calculation. Hill[7] has also put forward an equation for calculating the change in roll force due to tension based on a simplified form of pressure distribution. These theories are mentioned later; first, however, a simpler formula that does not involve a consideration of the pressure distribution will be derived.

The equation to the roll force may be written :

$$P_0 = \bar{k}f(R', h_1, h_2, \mu) \quad \ldots\ldots(7)$$

where k is the mean yield stress and $f(R', h_1, h_2, \mu)$ is a function of the geometry of the rolls and strip and the friction between them. It will be assumed that this function is unaffected by the application of tensions, so that when tensions are applied the expression becomes :

$$P = \bar{k}_t f(R', h_1, h_2, \mu) \quad \ldots\ldots(8)$$

where $\bar{k}_t$ is the apparent value of the yield stress. The mean yield stress may be calculated from the equation :

$$\bar{k} = \frac{1}{\alpha}\int_0^\alpha k.d\theta.$$

Suppose that, with tensions, the apparent mean yield stress is given by :

$$\bar{k}_t = \frac{1}{\alpha}\left[\int_{\phi_n}^{\alpha}(k - t_b)d\theta + \int_0^{\phi_n}(k - t_f)d\theta\right]$$

$$= \bar{k} - t_b - \frac{\phi_n}{\alpha}(t_f - t_b).$$

If, arbitrarily, $2\phi_n = \alpha$, this expression becomes :

$$\bar{k}_t = \bar{k} - \tfrac{1}{2}(t_b + t_f) \quad \ldots\ldots(9)$$

Combining equations (7), (8), and (9) :

$$P = P_0\left(1 - \frac{t_b + t_f}{2\bar{k}}\right) \quad \ldots\ldots(10)$$

Values of roll force calculated using equation (10) are given in column 8 of Table II, and the experimental values in column 7 ; the differences are in column 9. The required values of P_0 were obtained from the experimentally determined curve of roll force plotted against reduction %, shown in Fig. 3. The mean yield stress $\bar{k}$ was taken, after Bland and Ford,[10] as the yield in plane compression at the reduction $\bar{r} = 0{\cdot}4r_1 + 0{\cdot}6r_2$, where r_1 and r_2 are the total reductions before and after the pass.

Equation (10) implies that front and back tension have equal effects. This follows from the assumption that $2\phi_n = \alpha$, and leads to an underestimation of the effect of back tension. Whether these errors are tolerable or not will depend on the circumstances in which the formula is used. Being largely systematic, the errors are amenable to empirical correction.

Pressure Distribution Methods

Equations (3) and (10) require previous knowledge of the 'no tension' values of torque and roll force, respectively. In Orowan's general method of calculation, and in the more approximate method of Bland and Ford, the torque and roll force for any values of the tension may, in principle, be calculated directly from the geometry of the rolls and the strip and from the appropriate values of the yield stress and the coefficient of friction. The coefficient of friction, however, presents a serious difficulty, in that no satisfactory method of determining it in advance is available. In attempting to compare these methods of calculation with a series of experimental results, one must either choose an appropriate value for the coefficient of friction and assume that it does not vary from one experiment to another (an assumption for which there is very little supporting evidence), or must adjust the coefficient of friction for each experiment, in which case the comparison is valueless. No suggestion is made as to how this difficulty may be overcome. It is, however, possible to compare one method of calculation with another without reference to experiment, and it is instructive to examine the difference between the general method of Orowan[9] and that of Bland and Ford[10] when applied to rolling with tensions.

If the deformation of the strip is assumed to be homogeneous, and if the geometry of the strip and rolls, the reduction in the pass, and the coefficient of friction remain unaltered when tensions are applied to the strip, then the equation for roll pressure in Orowan's general theory for slipping friction may be written :

$$s^- = s_0^- - t_b \exp\left[\mu\left\{\psi(\alpha) - \psi(\theta)\right\}\right]$$

$$s^+ = s_0^+ - t_f \exp\left[\mu\,\psi(\theta)\right] \quad \ldots\ldots(11)$$

where the indices $-$ and $+$ denote quantities on the entry and exit sides of the neutral plane ; function $\psi(\theta) = \frac{2(1+\gamma)}{\sqrt{\gamma(2+\gamma)}}\tan^{-1}\left[\sqrt{\frac{2+\gamma}{\gamma}}\tan\frac{\theta}{2}\right] - \theta$; and $\gamma = \frac{h_2}{2R'}$. In cold strip rolling, $\frac{h_2}{2R'}$ is usually very small, and $\tan\theta \simeq \sin\theta \simeq \theta$, so that, without great error :

$$s^- = s_0^- - t_b \exp\left[\mu\left\{F(\alpha) - F(\theta)\right\} - \mu\left\{\alpha - \theta\right\}\right]$$

$$s^+ = s_0^+ - t_f \exp\left[\mu F(\theta) - \mu\theta\right] \quad \ldots\ldots(12)$$

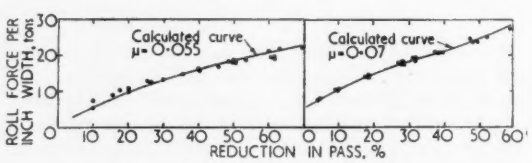

Fig. 3—Experimental values of roll force plotted against reduction in pass

where $F(\theta) = 2\sqrt{\frac{R'}{h_2}}\tan^{-1}\sqrt{\frac{R'\theta}{h_2}}$. It may be shown also that, when homogeneous deformation is assumed, the general theory of Orowan is identical with that of von Kármán.

The equations of roll pressure developed by Bland and Ford are an approximate solution to von Kármán's[11] equation, and using the above assumptions may be rewritten :

$$s^- = s_0^- - \frac{kh}{k_1 h_1} t_b \exp\left[\mu\{F(\alpha) - F(\theta)\}\right]$$

$$s^+ = s_0^+ - \frac{kh}{k_2 h_2} t_f \exp\left[\mu F(\theta)\right]. \quad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

(It should be noted that the corresponding quantities s_0 in equations (11) and (13) are not identical, each representing the normal roll pressure calculated by the appropriate method.) Bland and Ford,[10] however, have shown that over a wide range of rolling conditions where homogeneous compression may be reasonably assumed, their approximate solution to the pressure distribution for rolling without tensions agrees closely with the exact solution given by Orowan's general theory. The solutions may differ widely, however, when tensions are applied ; for an annealed strip which strain hardens appreciably, k may be much greater than k_1, so that :

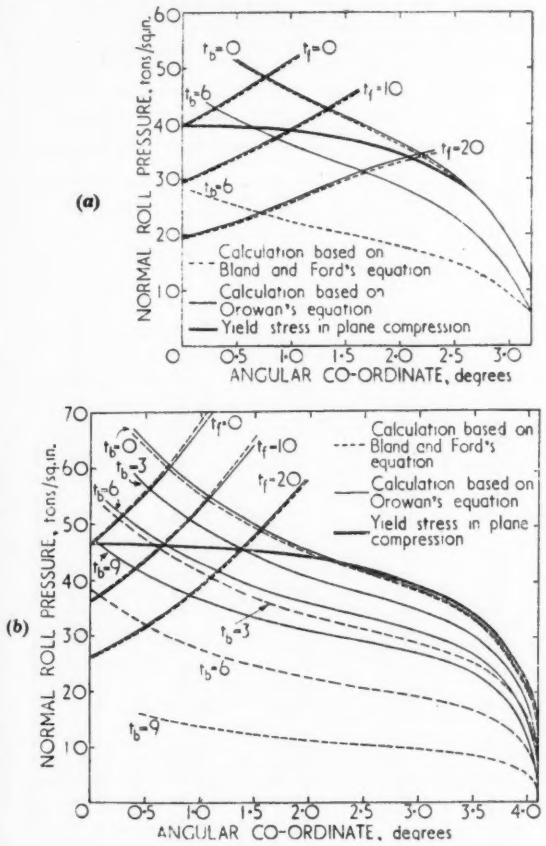

Fig. 4—Friction hill diagrams for annealed mild-steel strip: (*a*) 29·8% reduction ; (*b*) 48·7% reduction

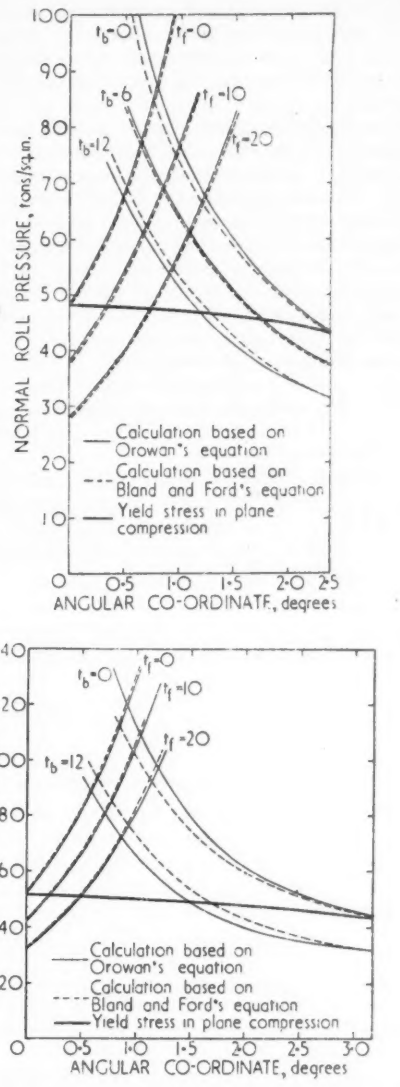

Fig. 5—Friction hill diagrams for prestrained mild-steel strip: (*a*) 32·3% reduction ; (*b*) 53·3% reduction

$$\frac{kh}{k_1 h_1}\exp\left[\mu\{F(\alpha) - F(\theta)\}\right] > \exp\left[\mu\{F(\alpha) - F(\theta)\} - \mu\{\alpha - \theta\}\right],$$

and, for an identical pass, s^- given by equation (13) will be lower than that calculated by equation (11), if the values of s_0 are identical. This is shown clearly in Figs. 4*a* and *b*, where s is plotted against θ for passes of 29·8% and 48·7% reduction on the annealed material. On the other hand, if the strip does not strain harden appreciably or has already been prestrained by previous rolling, so that $k \simeq k_1$, then :

$$\frac{h}{h_1}\exp\left[\mu\{F(\alpha) - F(\theta)\}\right] < \exp\left[\mu\{F(\alpha) - F(\theta)\} - \mu\{\alpha - \theta\}\right]$$

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so that equation (13) will overestimate s^-, in comparison with equation (11). This may be seen from Figs. 5*a* and *b*, which are friction hill diagrams for passes of 32·3% and 53·3% reduction on prestrained material.

In the construction of Figs. 4 and 5, the normal roll pressures were calculated from equations (11) and (13), using a constant value of the deformed roll radius. Suitable approximate values of the coefficient ot friction were obtained by comparison with the experimental results. These were found to be $\mu = 0{\cdot}055$ for annealed material and $\mu = 0{\cdot}07$ for prestrained material. Table IV shows the values of the roll force and torque calculated from these angular pressure distributions at various applied tensions, using the relationships:

$$P = R'\int_0^\alpha p.d\theta \quad \text{and} \quad G = RR'\int_0^\alpha p\theta.d\theta - \tfrac{1}{2}RT.$$

Hill's Roll Force Equation

In deriving a relationship between roll force and the strip tensions, Hill[7] takes as a first approximation that the normal roll pressure is everywhere reduced by the applied tensile stress, all other variables remaining unchanged, so that:

$$\left.\begin{aligned} s^- &= s_0^- - t_b \\ s^+ &= s_0^+ - t_f \end{aligned}\right\}, \qquad \text{.....(16)}$$

and he assumes that the neutral angle ϕ_n is not altered by the applied tensions. From this distribution of pressure, equation (3) may be deduced. A comparison between this assumed angular distribution of roll pressure and the distribution calculated from equation (11), is given in Fig. 6. Since s_0^+ is undefined by equation (16), its value has been chosen to agree with the value given by equation (11).

From an analysis of a simplified distribution of roll pressure, Hill[7] indicated that a relationship existed between the dimensionless groups G/PR and T/P, and showed that the equation:

$$\frac{G}{PR} = \frac{G_0}{P_0 R}\left[1 - \frac{T}{P\alpha}\right] \qquad \text{.....(17)}$$

agreed well with experiment. On eliminating G between equations (16) and (17), he obtained:

$$P = P_0 - \left[\frac{RP_0}{2G_0} - \frac{1}{\alpha}\right]T_f - \left[\frac{1}{\alpha} - \frac{(1-r)RP_0}{2G_0}\right]T_b \qquad \text{...(18)}$$

When the reduction and the component of roll pressure due to friction are both relatively small,

Table IV

ROLL FORCE AND TORQUE CALCULATED FROM ANGULAR PRESSURE DISTRIBUTIONS

Material	Coefficient of Friction	Reduction, %	Tensions, tons/sq. in.		Roll Force, tons per inch width of strip		Torque per Roll, tons-in./in. width of strip	
			t_b	t_f	Orowan	Bland and Ford	Orowan	Bland and Ford
Annealed M.S.	0·055	29·8	0	0	12·4	12·4	1·53	1·52
			0	10	11·2	11·2	0·36	0·35
$h_1 = 0{\cdot}063$ in.			0	20	9·0	8·9	−0·93	−0·94
			6	0	10·2	*	2·13	*
			6	10	9·6	*	1·01	*
			6	20	7·9	*	−0·195	*
		48·7	0	0	18·3	18·2	2·89	2·87
			0	10	17·0	16·9	2·03	2·06
			0	20	15·3	15·3	1·12	1·11
			3	0	16·6	14·2	3·07	2·33
			3	10	15·4	13·8	2·23	1·80
			3	20	14·4	12·8	1·35	0·95
			6	0	14·8	*	3·23	*
			6	10	14·2	9·6	2·41	1·58
			6	20	13·0	9·2	1·56	0·77
			9	0	12·8	*	3·39	*
			9	10	12·6	*	2·58	*
			9	20	11·9	*	1·75	*
Prestrained M.S.	0·07	32·3	0	0	18·1	17·9	1·78	1·75
			0	10	16·2	16·1	1·10	1·12
$h_1 = 0{\cdot}038$ in.			0	20	14·5	14·4	0·32	0·31
			6	0	16·1	16·1	2·13	2·12
			6	10	14·9	14·9	1·45	1·45
			6	20	13·2	13·2	0·72	0·72
			12	0	13·9	14·2	2·41	2·46
			12	10	12·5	12·7	1·79	1·83
			12	20	11·8	12·0	1·07	1·10
		53·3	0	0	25·8	25·0	3·21	3·01
			0	10	24·0	23·2	2·68	3·54
			0	20	21·9	21·5	2·11	2·03
			12	0	18·6	19·7	3·30	3·06
			12	10	17·6	18·6	2·83	2·61
			12	20	16·2	17·2	2·34	2·16

* No solution was possible in these cases, as the s^+ and s^- curves given by this method of calculation did not intersect

equation (16) will be a reasonably close approximation to equation (11) ; but at large reductions, where the frictional component is considerable, equation (16) will, in comparison with equation (11), overestimate the roll pressure. Moreover, the group G/PR is underestimated by equation (17) when the front tension stress is large, and this, in turn, leads to an overestimation of the roll force. Results from the nominal 50% pass on annealed material and 50% pass on prestrained material given in this form against the calculated lines in Fig. 7 show that the underestimation is considerable for the prestrained steel. Therefore, equation (18) overestimates the roll force when back tension is applied to the strip, and the error increases as front tension is added. This equation indicates a linear relationship between P and T_f or T_b; a relationship of this type is confirmed by observation.

DISCUSSION

Any attempt to discover useful methods of calculating the variables of the rolling process leads sooner or later to a dilemma. If the methods are based on a fairly exact analysis of the process, such as Orowan's general theory, they will involve lengthy computations. On the other hand, simplifications cannot be made without the risk of inaccuracy. As a first step to resolving this difficulty, some idea of the reproducibility with which the variables can be determined in practice is required. It has been found that, under the closely controlled conditions of laboratory rolling, the roll force may fluctuate within at least $\pm 0{\cdot}50$ tons per inch width and the torque within at least $\pm 0{\cdot}06$ tons-in. per inch width. These variables can hardly be expected to be held more closely in industrial rolling, and therefore the simplest methods of calculation that give errors of this order of magnitude may be used.

Measured by this standard, equation (3) :

$$G = G_0 + \frac{Rh_2}{2}(t_b - t_f)$$

is adequate except at very high values of the back tension, when the ratio of roll radius to entry thickness is of the order of 150 : 1 and more, and the strip is hard. This is due to the assumption that the energy of rolling is not affected by the application of tension. The assumption leads to little inaccuracy so long as the frictional part of the energy of rolling is small in comparison with the total, but as the ratio of roll radius to entry thickness of the strip increases, so does the ratio of frictional energy to total energy, and the tension, which affects only the frictional energy, begins to have an effect. The torque equation must therefore be used with caution when thin strip is being rolled between large rolls.

An important corollary to the assumption that the energy of rolling remains constant over a wide range of rolling conditions is that no advantage is to be obtained by rolling with applied tensions greater than those required to produce flat, properly coiled strip. Since the recovery of work done by the back tension is, in practice, incomplete, rolling with back tension will actually be less efficient than rolling without it.

The approximations involved in the roll force equation (10) :

$$P = P_0\left(1 - \frac{t_b + t_f}{2\bar{k}}\right)$$

are more sweeping than in the torque equation, particularly the assumption that the neutral angle is equal to half the angle of contact. The calculation of the true neutral angle is a lengthy and uncertain process, and some approximation of this kind is essential if simplicity is to be preserved. As may be seen from Table II, the errors involved in the use of this equation over a wide range of conditions are not much greater than the variation of $\pm 0{\cdot}5$ tons per inch width found during experimental rolling without tension, except that the effect of heavy back tension is underestimated.

Hill's roll force equation requires knowledge of the no-tension value of the roll force and also that of the no-tension torque, to a higher degree of accuracy than can normally be measured except in the laboratory; this is because the coefficients of T_f and T_b involve the reciprocals of the nearly equal small quantities α and $\frac{2G_0}{P_0R}$, so that slight errors in P_0 or G_0 may lead to large errors in the estimated value of P.

The above equations serve only to estimate the effect of tension on known no-tension torques and roll forces. For the direct calculation of torque and roll force under tension, the methods of Orowan and of Bland and Ford might be applicable but for the difficulty of determining in advance the coefficient

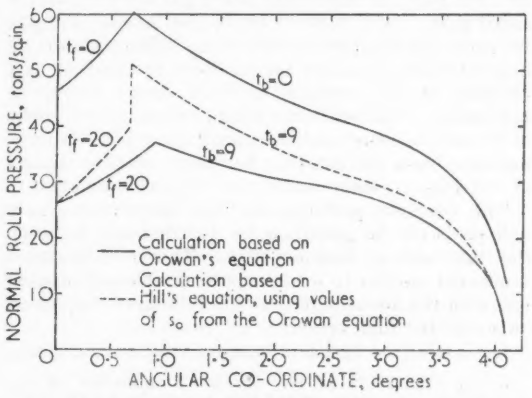

Fig. 6—Friction hill diagram for 48·7% reduction on annealed mild-steel strip

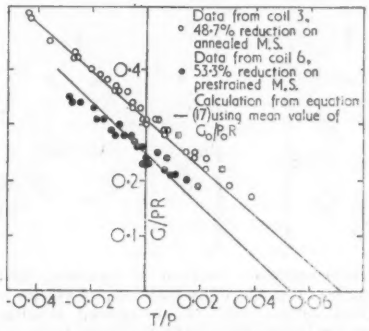
Data from coil 3, 48·7% reduction on annealed M.S.
Data from coil 6, 53·3% reduction on prestrained M.S.
Calculation from equation (17) using mean value of G_0/P_0R
G/PR
T/P

Fig. 7—Comparison of calculated and experimental values of G/PR plotted against T/P

of friction between the roll and the strip, a difficulty to which there seems at present to be no solution. Although these two methods give results for rolling without tension that agree closely, when heavy back tension is under consideration there may be substantial differences between them.

Acknowledgments

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A Tertiary Crusher for Soft Home Ores

By C. Lang, B.Sc.

TRIALS with a No. 3*a* Multi-hammer Pulverizer of the high-speed multi-hammer-type, supplied by Messrs. Edgar Allen and Co., Ltd., have been carried out at No. 3 Sinter Plant of Messrs. Stewarts and Lloyds, Ltd., at Corby. All the raw material (*i.e.*, sticky Northants ore, flue dust, and coke) to the plant was crushed. Experience gained in these trials suggested that a machine of this type could work fairly satisfactorily provided that the profile of the hammer tip was maintained.* It was found, however, that the 'build-up' of fines on the stationary breaker plate could stop the crushing when the hammer tip became worn. The hammer tips themselves always kept clean. Figure 1*a* shows diagrammatically the build-up on the stationary breaker plate experienced with the multi-hammer mill.

* D. W. Gillings, E. W. Voice, C. Lang, and P. K. Gledhill, *Journal of The Iron and Steel Institute*, 1951, vol. 167, April, pp. 400–439.

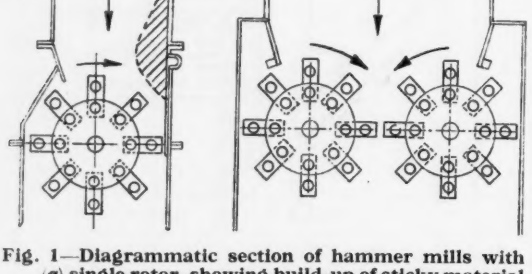

Fig. 1—Diagrammatic section of hammer mills with (*a*) single rotor, showing build-up of sticky material (hatched area), and (*b*) proposed double rotor, having no large stationary surfaces to cause build-up. In both types the hammers remain clean, even with sticky material.

It was also found that the crushing performance of the mill was virtually independent of the spacing between the breaker plate and the rotating hammers. It was believed, therefore, that most of the crushing of the material was dependent on the impact with the high-speed tip, the influence of the breaker plate being of secondary importance.

One approach to the problem of build-up is the use of a slowly moving breaker plate continuously rotating in the opposite direction to that of the high-speed hammers. Any build-up occurring is then brought down to the hammers.

Another approach might be the design shown diagrammatically in Fig. 1*b*. This comprises two hammer-mill shafts set up side by side, one shaft being adjustable. The shafts rotate at high speed in opposite directions, the ore being fed into the gap between the two sets of hammers. The stationary breaker plate is removed, although, if necessary, a small plate can be placed in, or just above, the gap between the two sets of hammers. There is thus no large stationary surface for the fines to build on, and choking of the crusher by this means would be prevented. The stationary walls receive very little of the ore, and they can be spaced at a relatively large distance from the rotating hammers, so that danger of build-up on these surfaces is relatively small.

The crushing performance and the crushing rate will probably be governed by the distance between the two sets of hammer tips. This mill becomes somewhat similar to a high-speed double-roll crusher but with the advantage that the hammers keep clean owing to the high speed.

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IRON AND STEELWORKS ENGINEERING

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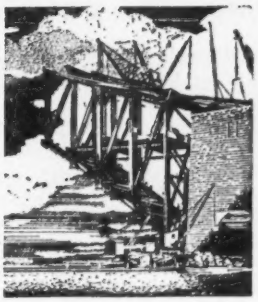

Protection of Structural Steel Against Atmospheric Corrosion

By J. C. Hudson and W. A. Johnson

SYNOPSIS

In this joint paper the protection of new structural steel against atmospheric corrosion is considered from two points of view. In the first part the approach is mainly theoretical and a brief account is given of the general principles that should be followed, as now established by the results of research. The approach in the second part is essentially practical. In it ways and means are considered by which these principles may be put to industrial use, bearing in mind the limitations and difficulties that are unavoidably imposed by industrial conditions. The conditions which a ' mass-produced ' coating should fulfil, and some dependable coatings, which are assumed to be painted later, in the usual way, are discussed.

PART I—GENERAL PRINCIPLES

By J. C. Hudson, D.Sc., F.I.M.

Introduction

In the last analysis, the principle underlying all methods of preventing the corrosion of metals by the atmosphere consists of covering the surface of the metal to be protected with a layer of material that is more resistant to atmospheric attack than the metal itself. This layer may form naturally as a result of the corrosion process or it may take the form of a deliberately applied protective coating, ranging in thickness from a thin paint film applied to a steel structure to concrete several inches thick surrounding a buried steel water main.

Two types of naturally protective layer may form on certain types of iron and steel. On nickel–chromium rust-resisting steels the layer consists essentially of chromium oxide and is so thin as to be invisible. Low-alloy steels show intermediate corrosion resistance and are not immune to rusting; their superiority over mild steel results because insoluble basic sulphates of the alloying elements (copper, chromium, nickel, etc.) accumulate in the rust, which becomes less permeable than the rust on ordinary steel.

For new structural steelwork, with which this paper is solely concerned, the two most important types of protective coating are paints and metallic coatings. Well-chosen coatings of both types have a marked natural resistance to breakdown. For example, painting schemes on steel have been observed to protect the metal perfectly for 15 years or more and a zinc coating 3 mils thick (2 oz. of zinc per sq. ft. of surface) should last for at least 25 years in a rural atmosphere.

The general principles underlying success in the protection of steel, both by painting and by the use of metallic coatings, have become clear from the investigations of the Corrosion Committee of the British Iron and Steel Research Association and its Protective Coatings Sub-Committee, and an attempt is now made to give a brief and non-technical account of these principles.

PROTECTION BY PAINT

The three factors essential for success in the protection of steel by painting are :

(i) Correct surface preparation of the steel to receive the paint
(ii) The choice of suitable painting schemes
(iii) Good painting procedure.

Types of Surface Preparation Available

The correct surface preparation of steelwork for painting is intimately associated with the fact that most steel plates and sections used are produced by hot-rolling, and it is inevitable that such steel should be covered with a thin layer of iron oxides, known as ' millscale.'

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Dr. Hudson is Head of the Corrosion Laboratory of the British Iron and Steel Research Association, Birmingham.

Millscale does not normally consist of homogeneous iron oxide but of three layers in each of which the iron is in a different state of oxidation (*see* Fig. 1). From the outside inwards, the composition of the three layers corresponds approximately to ferric oxide Fe_2O_3, magnetite Fe_3O_4, and ferrous oxide FeO. The thickness of the millscale varies according to the composition of the steel, the dimensions and type of section, and the rolling temperature (*e.g.*, 0·5–2·5 mils on $\frac{3}{8}$-in. sections of wrought iron or mild steel). Moreover, the proportions of the three oxide layers present in the millscale also vary from one material to another. These variations in thickness and composition of the millscale lead to differences in its resistance to attack by acids or by the atmosphere. Usually millscales formed at low temperatures are more resistant than those formed at higher temperatures. For example, Winterbottom and Reed[1] found that a 105-min. immersion in 3% by weight sulphuric acid at 55° C. was necessary to pickle off an oxide scale formed at 520° C., whereas a similar scale formed at 900° C. was removed in 40 min.

It is evident, therefore, that the properties of millscale will vary according to the section and the rolling conditions. It is also clear that the painting of structural steel may be done over (*a*) intact millscale, (*b*) a surface free from all millscale, or (*c*) partly intact millscale.

Painting Over Intact Millscale—In most cases the millscale on hot-rolled steel is not perfectly intact. It has been suggested that if paint were applied directly over the millscale this would provide a good key and constitute an additional barrier against corrosion. If this course were adopted, the ideal procedure would be to apply the priming coat of paint at the rolling mill shortly after the steel had left the rolls, while it was still warm. Unfortunately, this would hardly be practicable at existing rolling mills, and exposure tests have shown that the results are inferior to those obtained by other methods.

Painting Over a Surface Free From Millscale—Practical methods available for removing millscale from steel are of two kinds—physical and chemical. Physical methods include grit- and sandblasting, which knock off the millscale without producing much loss of actual steel. Machining or grinding also come in this category but their use for structural steelwork must be exceedingly rare.

To obtain the best results from blasting processes care must be taken to choose the correct operating conditions. This is a wide subject, which needs further study,* but, for the time being, two generalizations can be made. Firstly, the size and shape of the blasting particles should be correctly chosen in relation to the work in hand ; for example, when cleaning badly rusted steel the use of a too coarse grit may fail to remove the rust from the pits in the surface, which are merely bridged by the particles. Secondly, the blasting pressure should be correctly adjusted ; too much surface roughness, resulting from a too high pressure, may result in wasteful use of paint if adequate cover is to be obtained. In early work by the Corrosion Committee the use of Leighton Buzzard sand ejected by means of air at 12 lb. per sq. in. pressure through a $\frac{3}{8}$-in. dia. cast-iron nozzle held 3–6 in. from the work, proved an excellent method for preparing unrusted as-rolled iron and steel for painting.

The most common chemical method for the removal of millscale is pickling. As applied to structural steelwork the process is generally carried out by immersing the plates or sections in an acid bath at a suitable temperature and concentration. The mechanism of pickling is complex but the main effect of the acid is to dissolve the ferrous oxide layer next to the steel. This undermines the millscale and the rest flakes off. The attack of the acid on the steel itself can be reduced to negligible proportions by adding inhibitors to the pickling bath. Pickling is usually followed by a thorough rinsing with water or sometimes with slaked lime to remove the residual acid ; in some processes a final immersion is given in hot dilute phosphoric acid, which has the beneficial effect of producing a thin but slightly protective film of iron phosphate on the steel.

In all cases, whatever process is used, it is desirable to apply the priming coat of paint to the freshly cleaned metallic surface.

The weathering of hot-rolled steel may be regarded as a chemical method of descaling, but as this procedure seldom leads to complete removal of the millscale, it is more appropriately considered below.

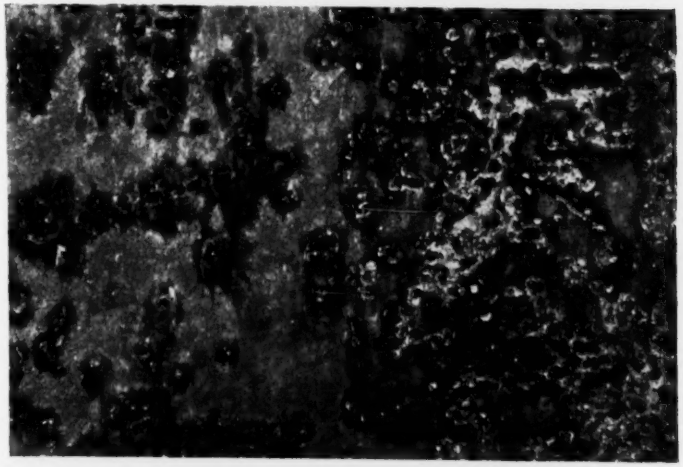
Painting Over Partly Intact Millscale—In most practical cases, unless the steel is gritblasted or pickled, it will be painted over a partly intact millscale. This is the surface condition that almost always results from weathering followed by cleaning with scrapers and wirebrushes.

The duration of exposure necessary to remove millscale completely by weathering varies with the climate and is also affected by the type of millscale, the thickness and shape of the section, and the position of the section in relation to the whole structure if weathering takes place after erection. As a rough guide, it may be noted that the time needed to remove 95% of the millscale from $\frac{3}{8}$-in. thick hot-rolled mild steel was observed to vary from about six months in industrial atmospheres in Great Britain to more than five years in certain tropical climates. These are maximum rates of weathering because the test specimens were freely exposed.

It is improbable that complete descaling by weathering of an actual structure could be achieved within about two years, bearing in mind the varied types of millscale that would be present on individual members and that some of these members would be in sheltered positions. In an industrial atmosphere mild steel may rust at the rate of 5 mils/yr., or more. It is evident, therefore, that the long weathering periods required to remove the millscale completely will also lead to appreciable rusting of the structure. This renders it impracticable to remove the rust completely by normal hand-cleaning methods, because some will remain trapped in pits. Indeed, experiments have shown that the weight of rust remaining

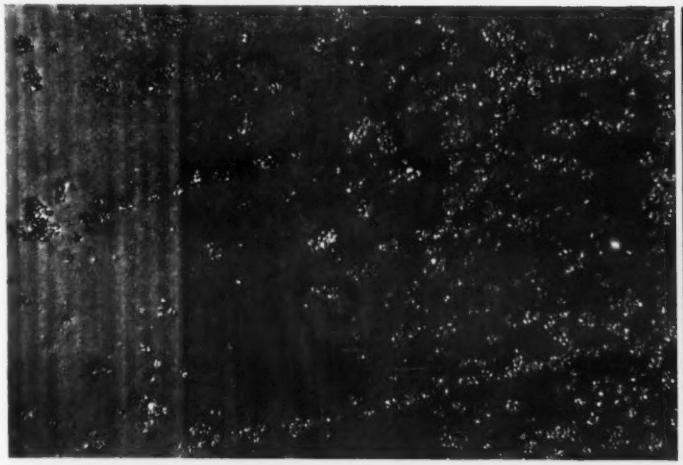
* Work in this field is in progress in the United States under the auspices of Sub-Committee TP-6G—Surface Preparation for Organic Coatings—(Chairman Mr. A. J. Liebman) of the National Association of Corrosion Engineers.

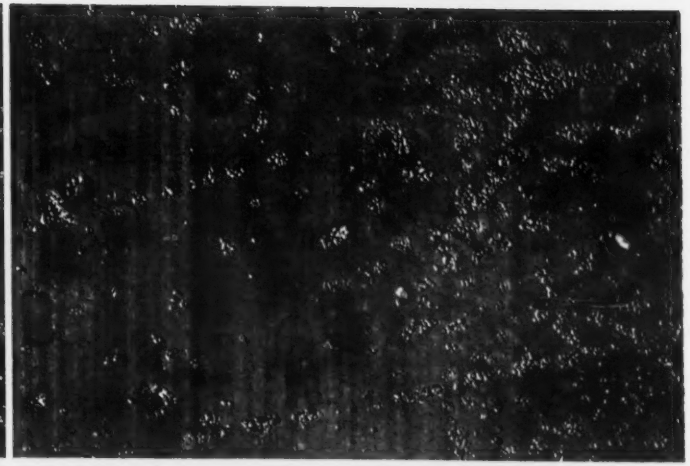
Fig. 1—Structure of millscale on the upper surface of a ¾-in. flat of 0·2% carbon steel. Finishing rolling temperature 980° C.; total thickness of millscale approx. 1·8 mils × **1000**



(a)

(b)





(c)

Fig. 2—Correlation of paint failure on weathered ¼-in. mild-steel plate with original surface condition : (*a*) Condition before painting after 6 months' weathering; (*b*) condition of paint film after 6 weeks' exposure ; (*c*) condition of paint film after 4·8 years' exposure

[Hudson and Johns
[To face p. 1.

on a weathered steel surface, after the most careful cleaning, is roughly equal to that of the millscale that has been shed during exposure and that, when weathering in an industrial atmosphere is prolonged sufficiently to produce complete descaling, the loss of steel may be equivalent to a reduction in section of about 2%.

Recently, a procedure has been adopted in which weathering is combined with flame-cleaning (*see* p. 168). The result, if the weathering period is not unduly prolonged and the flame-cleaning is carried out immediately before painting (as it should be), is to give a good surface for paint application that is not greatly inferior to the surfaces resulting from pickling or blasting.

Effect of Surface Preparation on Paint Durability

Research has shown that surface preparation is by far the most important single factor influencing the duration of protection afforded to structural steel by a painting scheme. The magnitude of the differences that may result from the adoption of different methods is illustrated by the experimental results given in Table I. These relate to two different painting schemes applied to a range of structural irons and steels exposed outdoors in an industrial atmosphere at Sheffield. The shortest duration of effective protection was observed when the paints were applied to weathered surfaces. These 'lives' were roughly five times shorter than those observed when the irons and steels were descaled by sandblasting. Moreover, although the lives of the painting schemes applied over intact millscale were considerably greater than those applied over a weathered surface, they were appreciably inferior to those on descaled surfaces, whether prepared by pickling or sandblasting. The reasons for these striking differences may be simply explained by reference to Fig. 3.

(*a*) Paint applied over intact millscale may have a long life, but there is always the danger that the millscale will lift locally at weak points and carry away the paint film with it.

(*b*) After weathering and wirebrushing, pieces of millscale, interspersed with areas of rust are left on the steel surface. The paint soon fails at the boundaries of the millscale, which is levered up by rust creeping beneath it. When the millscale flakes off it carries the paint film away and effective protection is at an end. The points of failure of paint applied over a weathered surface correspond with the boundaries of the areas of millscale left on the steel at the time of painting (Fig. 2). The smooth light grey patches in Fig. 2*a* are intact millscale and the dark craters are places where the millscale had been shed and the steel had rusted ; they are surrounded by rings where the millscale had been stained by rust but was still in position. After the plate had been photographed, it was wirebrushed and painted with two coats of paint. Figure 2*b* shows the plate after six weeks' exposure in the open. Fine blisters had developed beneath the paint film. The positions of these blisters corresponded exactly with the positions of the craters (rust-spots) in (*a*), and no blisters developed at areas where the millscale was intact at the time of painting. After nearly five years' exposure (Fig. 2*c*), the blisters had swollen slightly but no local failure (bursting) of the paint film had occurred. No new centre of blistering had arisen : the rust and broken millscale entrapped beneath the paint film would be eventually responsible for its failure.

(*c*) If the millscale is entirely removed by weathering —which is unlikely—much rust remains on the surface after cleaning and becomes trapped beneath the paint film. Although rust is much less harmful than millscale, it is liable, nevertheless, to lead to failure of the paint film. This is because the rust consists essentially of various oxides and hydroxides of iron, which react gradually with moisture and oxygen diffusing through the paint film from the atmosphere. As a result, the rust expands, giving rise at first to

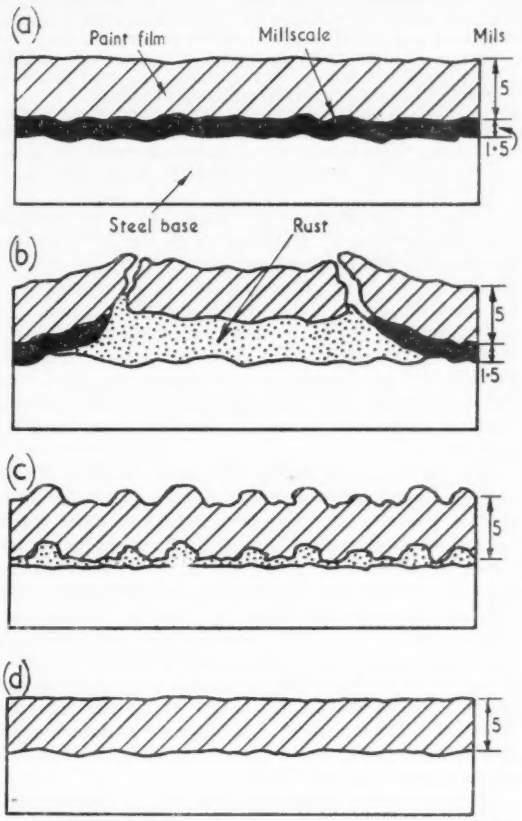


Fig. 3—Effect of surface preparation of steel on paint performance: (*a*) Intact millscale; (*b*) broken millscale and rust; (*c*) rust only, no millscale; (*d*) rust-free, descaled surface

Table I

EFFECT OF SURFACE PREPARATION ON THE DURABILITY OF PROTECTIVE PAINTING SCHEMES

Surface Preparation	Durability, years	
	4-Coat Scheme (2 coats of red lead paint and 2 coats of red iron oxide paint)	2-Coat Scheme (2 coats of red iron oxide paint)
Intact millscale	8·2*	3·0
Weathered and wirebrushed	2·3	1·2
Pickled	9·5*	4·6
Sandblasted	10·4	6·3*

* Indicates that at the most recent inspection the painting scheme had not failed on all the surfaces concerned

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a fine blistering of the paint film. If the amount of rust is not too great and the properties of the painting scheme are good, rupture of the paint film may not occur. At its best, however, this form of surface preparation is not to be recommended, and in many practical cases it leads to premature failure.

(*d*) When paint is applied to steel immediately after it has been freed from millscale by pickling or gritblasting, there is no rust or millscale beneath the paint film and the maximum duration of protection is achieved.

Value of Descaling—It is evident that some method such as pickling or gritblasting is the best surface preparation for painting structural steel. Numerous variations of both processes are in industrial use; for example, hydrochloric acid, phosphoric acid, and sulphuric acid can all be used for pickling. Research has shown, however, that variations in the descaling process are of secondary importance, provided that the process ensures the application of the priming coat of paint to a perfectly descaled and unrusted surface.[2]

Phosphating and Other Chemical Surface Treatments—Phosphating is widely used (*e.g.*, in the automobile industry) for the preparation of steel sheets for painting. The steel is degreased and, if necessary, descaled and is then treated with a phosphating solution, either by dipping or by spraying. The solution consists essentially of phosphoric acid and phosphates of iron, manganese, or zinc, according to the individual process. Accelerating agents are added to some solutions. The operation is usually carried out at about 80° C., also to speed up the reaction. The thin adherent layer of phosphates has some slight protective properties but its main value is that it is an excellent basis for paint.

There is no reason why the use of phosphating processes should not be extended to heavy structural steel, although the size, weight, and variety of the components to be treated may impose certain limitations. The so-called surface washes, which are sometimes advocated as a substitute for phosphating, do not suffer from these possible disabilities, because, as a rule, they are applied cold. A typical non-proprietary formulation is 33·3% phosphoric acid, 1·7% chromic acid, 6·7% butyl cellosolve, 58·3% water, by weight.

Without prejudice to individual proprietary products of this nature, it would seem that the useful application of surface washes of the phosphoric acid type to heavy structural steel (as distinct from sheet steel) is limited. The protective value against atmospheric corrosion of the films they form in the cold cannot be expected to equal that of the films produced by hot-phosphating processes. Surface washes are of value in counteracting the effects of slight surface rusting, such as may develop when bright steel is stored indoors for some time, but it is improbable that they will restore a badly rusted surface, or, what is worse, one carrying broken millscale and rust, to a condition fit for painting.

Flame-cleaning—Flame-cleaning was first used about ten years ago for the preparation of structural steelwork for painting. The process consists of directing the intense flame of an oxyacetylene torch on to the surface of the steel. For flat surfaces a row of small brush-like flames issuing from multiple burners is used. This is moved across the surface with a reciprocating action at a forward speed of about 10 ft./min. The effect of the flame, which impinges on the surface at an angle of about 45°, is twofold : it causes all loose millscale to flake off and any rust on the surface is strongly dehydrated.

After the passage of the flame, the surface is thoroughly wirebrushed to remove any remaining loose millscale and rust. The priming coat of paint is applied shortly afterwards while the steel is still warm. This prevents condensation of atmospheric moisture on the surface and has the advantage of expediting the drying of the paint film.

It is too early, as yet, to make a final judgment on the merits of flame-cleaning as a method of surface preparation, but practical experience has already shown that it is both advantageous and effective when applied to suitable work. The surface obtained on new steel in reasonably good condition is little inferior to that resulting from gritblasting, so far as the subsequent behaviour of protective painting schemes is concerned.

Temporary Protective Coatings

If, for any reason, painting cannot follow immediately after the surface preparation of the steel, serious corrosion of the bare steel surface can be prevented for a fairly short period by the use of temporary protective coatings such as linseed oil. Tests have shown that thin coats of boiled linseed oil will protect steel adequately for about three months when exposed outdoors under mildly corrosive conditions. It is important that the oil should be applied thinly (at about 1 gal./3000 sq. ft.), by rubbing it on or by diluting it with a volatile solvent for brush application. Such thin coatings are readily absorbed into the priming coat of the final painting scheme but thicker coatings of neat linseed oil are objectionable, because it is difficult to remove them before painting.

CHOICE OF SUITABLE PAINTING SCHEMES

Quality of protective power should be the first criterion governing the choice of paints. In most cases the cost of the paint materials forms but a small proportion, say one-tenth, of the total cost of the painting operation, and if the use of a more expensive paint results in an appreciable prolongation of the protection given to the structure, its purchase will prove more economical in the long run.

Paint technology is a rapidly growing science and new materials—pigments, resins, and media—are constantly being introduced. These are immediately incorporated by the paint industry in new and, on the whole, better paints. Consequently, it is held by some practical men that it would be a retrograde step to tie down the use of protective paints for structural steelwork to a limited number of hard and fast paint formulations and that the individual paint manufacturer should be left free to give full scope to his experience and ingenuity. The author has a good deal of sympathy with this view. It is certain that in choosing a protective scheme for a given purpose, the user will be well advised to seek and adopt the advice of the paint manufacturer. At the same time it may be helpful to state certain general principles that should be observed when selecting paints for

structural steelwork and to record a few reliable formulations.

Priming Paints

Value of Inhibitive Priming Paints—The best results are obtained when the priming paint applied to the steel surface is pigmented with materials that repress the tendency of iron to corrode, *i.e.*, inhibitive paints. Red lead, white lead, basic lead sulphate, the chromates of lead, zinc, and other metals, zinc dust and possibly zinc oxide are inhibitive pigments. They act by stifling corrosion at its birth, probably by causing the precipitation of an insoluble compound, *e.g.*, an iron oxide or hydroxide, which is precipitated at the seat of incipient corrosion and thus prevents further attack.

It should be stressed that a paint containing a mixed pigment will often prove superior to one containing but a single pigment. Even with neat red lead, the judicious addition of extenders, up to say 20% by weight, may have a beneficial effect on the ease of application and the stability of the paint, without seriously impairing its protective value. However, too much dilution of the inhibitive pigment has a harmful effect on the protective properties of the paint.

Formulation of Priming Paints—Comparative exposure tests of nearly 200 priming paints for structural steelwork have been undertaken since 1945.[3] From observations of the first series of these tests covering up to three years' exposure, both in an industrial atmosphere at Derby and in a marine atmosphere at Brixham, it may be concluded that the six paints whose formulations are given in Table II are among the best of those tested. These paints vary only in their pigmentation ; in all cases except paint No. 300 the medium was a blend of linseed stand-oil (30 poise) with alkali-refined linseed oil in the proportion of 2 parts to 3 parts by weight. The medium of paint No. 300 consists of equal parts of acid-refined linseed oil and pale boiled linseed oil. It is surprising that paints bound with more modern types of medium, incorporating various synthetic resins and other drying oils, have not been found to give any better results. A choice between the six paints listed in Table II is unwarranted at this stage, but, if a choice had to be made, it is possible that paint No. 321, pigmented with red lead, white lead, and asbestine, might prove the most useful for all-round service.

These tests have been made on steel prepared for painting by the usual practice of exposing it to the weather and wirebrushing it immediately before painting. Correct surface preparation widens the available choice of priming paints and tends to level out the differences in their performance. Thus, the difference between the performance of an inhibitive priming paint and that of a non-inhibitive one is much less marked when the painting schemes are applied over descaled and unrusted surfaces, such as are obtained by pickling or gritblasting. For example, in a test made in a suburban atmosphere two coats of paint pigmented with the non-inhibitive pigment, micaceous iron ore, were found to give perfect protection to pickled wrought iron for 15 years.

Table II

FORMULATION OF PRIMING PAINTS FOR STRUCTURAL STEELWORK

Pigment	Weight, %					
	Paint No.					
	302	323	316	306	321	300
Basic lead chromate	20	20	...	...	...	...
Basic lead sulphate	60	...	...	...	...	...
Red lead	...	...	...	80	40	100
White lead	...	...	...	...	40	...
Zinc chromate	...	...	20	...	...	...
Zinc oxide	...	60	60	...	...	...
Extender (Asbestine)	20	20	20	20	20	...

Finishing Paints

The main function of a finishing paint is to protect the priming paint and to enable this to exert its inhibitive effect on the steel for the longest possible time. Thus, although inhibitive pigments are unnecessary in a finishing paint, it is essential that it should be highly impermeable to atmospheric moisture and gases, and as resistant as possible to weathering. Moreover, any painting scheme must be studied and formulated as a whole, and it is not the best practice to bring together an indiscriminate collection of coats of paints of various types, however good each coat may be individually.

Formulation of Finishing Paints—Tests of the Corrosion Committee and of similar organizations abroad have demonstrated that finishing paints pigmented with red oxide of iron, white lead, aluminium powder, or micaceous iron ore and bound with linseed oil media, particularly of the stand-oil type, will give a good performance when applied over inhibitive priming paints such as red lead. Typical formulations that have behaved well in exposure tests will be found in Table III.

Tars and Bituminous Paints

For some industrial purposes tars and bituminous paints form a useful alternative to oil paints for the protection of structural steelwork. It is doubtful whether any paints of these types have inhibitive properties, so that, as a rule, they are best used as finishing coats over an inhibitive primer, red lead paint being most commonly used for this purpose. The priming coat should be allowed to dry for at least one month before the tar or bituminous paint is applied, to avoid lack of adhesion between the two coats.

Little systematic work has been published on the formulation and performance of tar and bituminous paints. It is hoped that some systematic tests on 55 paints of known formulation that were undertaken in 1948[3] may add to our knowledge of the subject.

PAINTING PROCEDURE

Importance of Good Painting Conditions

To obtain the best results, all painting should be carried out when the air is reasonably warm, say at a temperature of 60° F. or higher and when the

Table III

FORMULATION OF FINISHING PAINTS FOR STRUCTURAL STEELWORK

	Weight, %					
	Corrosion Committee	Swedish Corrosion Committee*			Dutch Corrosion Committee	U.S. National Bureau of Standards
Pigment						
Aluminium powder	...	10	11	15	4	...
Chromium oxide	...	...	...	...	...	12
Micaceous iron ore	...	45	49	...	32	...
Red iron oxide (76% Fe_2O_3)	65	...	...	...	...	...
White lead	...	...	...	37	...	59
Medium						
Raw linseed oil	...	...	...	...	...	25
Refined linseed oil	14	...	...	...	...	...
Boiled linseed oil	14	...	30	...	...	...
Linseed stand-oil	...	...	10	...	...	...
1/3 tung-linseed stand-oil	...	45	2	48	40	...
Spar varnish	...	...	...	...	...	3
Thinners	4	...	...	...	22	1
Driers	3	...†	...	...	2	...

* Figures refer to unthinned paints. Thinning may be necessary to produce a suitable brushing consistency
† The addition of 2% of liquid driers is recommended

relative humidity is below about 80%. It is advantageous, therefore, to paint under cover, and whenever practicable every effort should be made to ensure that new steelwork receives at least its initial priming coat of paint under good conditions in the shop.

When the final painting of the structure is done after erection, some compromise will generally prove necessary between what is desirable and what is practicable. Nevertheless, much can be done to ensure that the painting of steelwork takes place under favourable conditions even when conducted outdoors. Any little extra trouble taken in this way will be amply repaid by the better results obtained. The variation in the atmospheric humidity throughout the year at Kew Observatory, shown in Fig. 4, makes it clear that in Great Britain the best period for painting is from April to September inclusive and that the months of November, December, and January should be rigorously avoided. Similar records of relative humidity are available for most parts of the world and it would be wise to consult them when planning the painting of structures overseas.

Comparison of Different Methods of Paint Application

Dipping is seldom used for the application of paint to structural steelwork, but spray painting and brush painting are commonly practised. The suitable choice of these methods depends on the nature of the work and the prevailing conditions, especially as some types of paint are only suitable for brush application.

Spraying is generally the quicker method and, on the whole, yields a more uniform coating with the normal type of paint. The brush marks resulting from brush application are a source of weakness. Spray painting is more sensitive to adverse weather conditions than brush painting, because the adiabatic expansion of the paint emerging from the spray nozzle may lead to the trapping of water within the paint film. There is no reason, however, to believe that when both methods are operated under good conditions there is any marked difference in their efficiencies. In comparable tests, made by F. Fancutt,[1] on a limited range of specimens coated by both methods with the same painting scheme, sprayed coatings give a slightly better performance on exposure, but the difference may well have been associated with the greater weights of paint, which were applied by spraying.

In any given case the choice between the two methods of application should be governed by practical circumstances associated with the nature of the work involved.

Importance of Adequate Paint-Film Thickness

In most cases the durability of a protective coating increases with its thickness (*see* Fig. 5). The results shown relate to one of the tests undertaken by Joint Technical Panel J/P1, in which 100 different priming paints were applied to weathered steel and overcoated with a single coat of the same finishing paint. The specimens were exposed to the atmosphere at

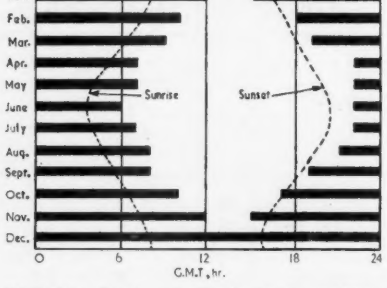

Fig. 4—Variation in the atmospheric humidity at Kew Observatory. The black bars show the periods of the day when the relative humidity of the air exceeds 80%

Derby (industrial atmosphere) and at Brixham (marine atmosphere). Each bar in the diagram represents an average for 10 to 20 painting schemes of about the same total film thickness.

It is deduced that no steel structure should go into service carrying a paint film less than 5 mils thick, *i.e.*, 3 or 4 coats. The priming coat should be of adequate thickness, say 1·5 mils, so as to cover the natural roughness of the steel surface.

It is important to be able to check that a satisfactory paint-film thickness has been achieved. This can be done either by calculation or by measurement.

Calculation of Paint-Film Thickness—The average thickness of a coat of paint can be calculated with reasonable accuracy from the formula :

$$t = 1930N(1 - Dv/d)/A,$$

where

t = average film thickness in mils (0·001 in.)
N = quantity of wet paint applied to an area of A sq. ft. (gallons)
$100v$ = percentage by weight of volatile matter in the wet paint,

and

D, d = specific gravities (or weights in lb./gal.) of the wet paint and the volatile matter, respectively.

If they are not known, the values of D and $100v$ can be determined by simple laboratory tests. Generally a figure of 0·78 may be assumed for d.

Measurement of Paint-Film Thickness—In some cases paint-film thickness may be determined directly on strips of paint removed from the structure itself. Non-destructive methods are preferable and several instruments are available. Most of them depend on electric or magnetic principles. For example, in one of them—the Armament Research Establishment thickness tester shown in Fig. 6—the thickness of the coating is deduced from its effect on the attractive force between a permanent magnet and the steel base. The magnet is attached to one extremity of a small lever and the pull necessary to detach it from the painted surface is determined from the movement of jockey weight. The thickness of the paint film is deduced from the position of the weight at the point of break by means of a calibration curve.

The main difficulty in the use of these instruments is that of making them suitable for work in the field. For example, the A.R.E. thickness tester can only be used in a horizontal position. The presence of millscale, and to a less degree of rust, beneath the paint film, interferes with the accuracy of measurement. Moreover, the measuring heads of the instruments are liable to press into the paint film, particularly in the case of the relatively soft air-drying films commonly used for structural steelwork. Despite these limitations, when used under correct conditions the best instruments of this type are capable of measuring the thickness of suitable paint films with an accuracy of 10%.[4]

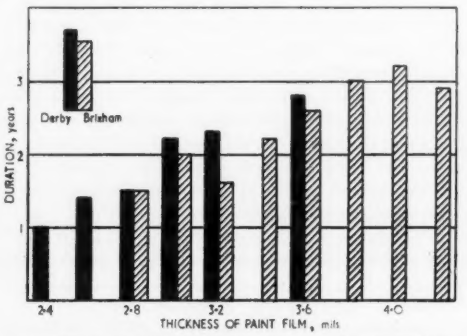

Fig. 5—Effect of film thickness on the durability of protective painting schemes

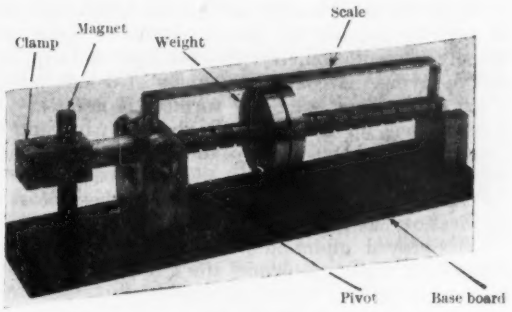

Fig. 6—The A.R.E. thickness tester

METALLIC COATINGS

Value of Metallic Coatings for the Protection of Steel

The value of protective metallic coatings arises mainly from three causes. Firstly, the non-ferrous metals commonly used as coating materials, zinc, aluminium, lead, etc., are much more resistant to atmospheric attack than mild steel itself. For instance, zinc is from 5 to 20 times less corrodible than iron in the open atmosphere. Secondly—and this is a great merit—metallic coatings have a much greater resistance to mechanical damage and abrasion than ordinary paint films. Thirdly, suitably chosen and properly treated metallic coatings form an excellent basis for painting (few commercial metallic coatings are everlasting, and further protection by painting will be needed).

Tests by the Protective Coatings Sub-Committee

The choice of metallic coating for use on heavy structural steelwork is severely limited by several practical considerations, the most important being that of cost, which will be discussed in the second part of this paper. It is desirable that the coating metal shall stand in the correct electrochemical relationship to iron, so that the coating shall protect the steel and not tend to increase its rusting, once the coating has become perforated either by corrosion or by damage. But, although this factor is vital for underwater work it may not be so important when the structure is exposed solely to atmospheric attack.

An investigation of five coating metals regarded as suitable for use on heavy structural steel, namely aluminium, cadmium, lead, tin, and zinc, and some of their alloys, was begun in 1940 by the Protective Coatings Sub-Committee. The coatings were applied to 15 in. × 10 in. × $\frac{3}{8}$ in. mild-steel flats, which were then exposed to the open air in various localities at home and overseas. An interim report on their behaviour covering the first five years' exposure was published in 1946,[5] and the following provisional conclusions were reached :

(1) As a coating metal, zinc has the advantage that it can be applied by several different processes, namely cementation, electrodeposition, hot-dipping, and spraying. A coating thickness of 3 mils (about 2 oz. of zinc per sq. ft. of surface) is necessary to protect steel for five years at Sheffield ; in rural or marine atmospheres the lives of such a coating would be considerably longer. In general, coating life is determined by the coating weight and the process of application has a relatively minor effect.

(2) Sprayed aluminium coatings also give good results ; a coating 3·6 mils thick (about 0·8 oz. of aluminium/sq. ft.) would be necessary to ensure five years' protection at Sheffield.

(3) Coatings of lead and terne alloy (88% lead, 12% tin) give protection in industrial atmospheres such as Sheffield, probably because of the formation of a protective film of lead sulphate. They are less satisfactory in rural and marine atmospheres, where this protective film does not form.

Metallic Coatings as a Basis for Paint

The use of metallic coatings for the protection of structural steelwork will probably extend rapidly, especially as a result of the recent introduction of semi-automatic methods of metal spraying, which have enlarged the scope and lessened the cost of this process. The large-scale use of metallic coatings on structural steelwork will raise new problems because, sooner or later, the coatings themselves will need protection. It is evident that painting schemes designed for use over bare steel are not necessarily the most suitable for a protective metallic coating. For example, it is doubtful whether red lead paint should be used on zinc-coated steel or, indeed, over other metallic coatings.

The choice of suitable priming paints for use over metallic coatings, as distinct from mild steel, is being investigated by Joint Technical Panel J/P1.[3] In a series of tests, commenced in 1948, five priming paints of different types were applied to bare steel and over steel that had been coated with aluminium (by spraying), terne alloy (by hot-dipping), and zinc (both by hot-dipping or spraying). In the case of the bare steel and of the zinc coatings various methods of surface preparation for painting, such as phosphating, are also being tested.

It is too early to draw even interim conclusions but it may be appropriate to add a few remarks about the painting of hot-galvanized steel.

It is common knowledge that paints may not adhere well to freshly prepared hot-galvanized surfaces. This may be partly due to certain reactions between zinc and the paint medium, but the main factors are probably the smoothness of the surface and the presence of grease and flux from the galvanizing bath. It is advisable, therefore, to use special treatments, *e.g.*, hot-phosphating, when preparing new hot-galvanized steel for painting.

However, phosphating cannot be readily applied to heavy structural steelwork and resort is generally had to surface washes. Various solutions, differing widely in composition, are in use. Amongst these a non-proprietary wash of 5% commercial hydrochloric acid, 5% carbon tetrachloride, 30% toluol, and 60% denatured alcohol, by volume, has been stated to give good results. The solution is brushed on, and after it has dried the surface is wiped over with a dry cloth.

Alternatively, it is good practice to allow hot-galvanized steel to weather in the open for some months before painting it. The minimum time needed naturally depends on the local climatic conditions, but about three months in industrial atmospheres and up to one year in less corrosive atmospheres should suffice.

A third solution of the problem is to use priming paints that adhere well to hot-galvanized surfaces, even in the absence of special preparatory treatments. Claims have been made in the United States that paints pigmented with mixtures of zinc dust and zinc oxide have this property and a U.S. Federal Specification[6] exists for paints of this type.

PART II—PRACTICAL APPLICATIONS

By W. A. Johnson, M.A., M.I.C.E., M.I.Mech.E.

Introduction

A VAST corrosion literature has been assembled during the last half-century and Part I of this paper is a typical summary of work of this character as it relates to the atmospheric corrosion of new structural steel. Much of the work has been of a chemical character, and has resulted from researches in many countries. The civil and mechanical engineer does not need to be fully aware of all this fundamental background but he certainly enters the field in regard to its application, today.

In all practical considerations of the methods of protecting structural steel against corrosion, the economics are of the utmost interest and importance. An attempt is made here to indicate the average order of cost of various processes based on data relative to a series of actual constructions ; in other cases tentative estimates regarding processes as yet only partially developed are given. For fair comparison, all costs are calculated on an area basis, although structural engineers and others would probably be more interested in the cost per ton. For this reason Fig. 7, which relates cost per sq. ft. to cost per ton, is included. With a thickness of just a little less than $\frac{1}{2}$ in. the cost per ton is £1, for each 1*d.*/sq. ft. of surface treated. From this common starting point propor-

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Mr. Johnson is Development Engineer in the Research and Development Department of The United Steel Companies, Ltd., Rotherham.

tional adjustments can be made for all thicknesses. To remove all ambiguity protective coatings are compared on a thickness basis.

The use for structural purposes of steels, which are highly resistant to corrosion would, except in special applications for chemical plants, be grossly uneconomic in first cost, but with little or no maintenance they might well have served their purposes and become obsolete before they suffered any serious deterioration in strength. On the other hand, in an industrial area the exposed use of structural mild steel (*e.g.*, B.S. 15 and 153) will usually involve the periodic application of paint for preservation and/or appearance. The total maintenance cost (although it may be an economic convenience to have it spread over half a century) may very nearly approach the first capital cost. In many such instances a case may be found for an enhanced initial capital outlay for protective measures, which may be more than recovered by reduced subsequent maintenance expenditure.

A consideration of the protection of mild structural steel depends on the life of the paint applied and not on the corrosion of the steel, except when this may influence the life of the paint. Steel, which is not protected by paint, is usually embedded either in concrete or masonry, and in these circumstances corrosion should not be severe if the design and workmanship are good and if there is a satisfactory depth of cover.

The structural designer can help to minimize corrosion by the avoidance of crevices and ledges, which will act as traps for moisture and dirt, by the avoidance of contact between dissimilar metals, by good ventilation to minimize condensation, and by ensuring easy access to all parts of the structure for regular inspection and repainting.

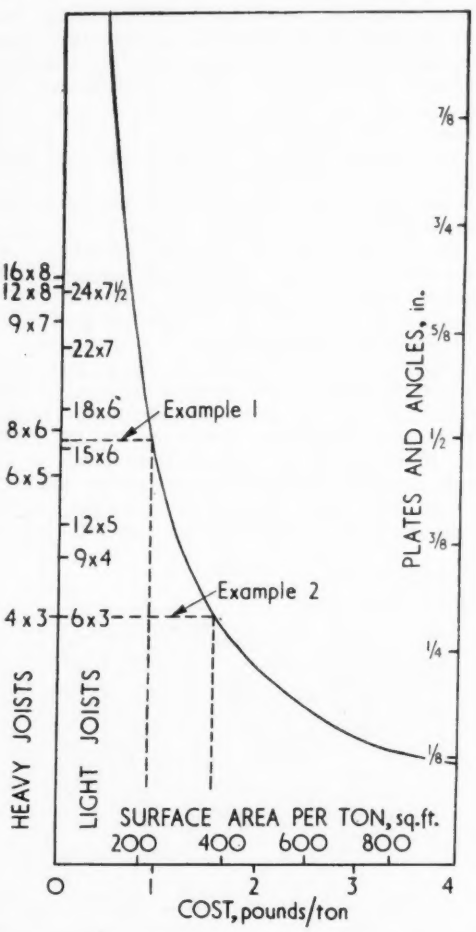

Fig. 7—Section size and thickness in relation to surface area and cost of treatment

SCOPE FOR LOW-ALLOY STEELS

It might be thought that low-alloy, corrosion-resistant steel would offer a better solution to the corrosion problem than to strive after well prepared and treated mild steel. There is little difference, however, between low-alloy steel and mild steel in the initial stages of corrosion. The corrosion resistance of low-alloy steel is dependent on the stability and physical strength of the rust film which is formed on exposure, and which appreciably retards further rusting. Low-alloy steels combine, in various measures, corrosion resistance and high yield point, and for this reason, if use can be made of the additional permissible stress, they have a potential competitive advantage over mild steel. When working with a high stress in thin sections, any corrosion is liable to affect the strength of the structure, and a proper protective painting scheme should be applied to offset this danger.

Paint applied to similarly treated mild and low-alloy steels, whether for protective or aesthetic reasons, would be expected to have a somewhat similar life, so that all the arguments in favour of scale and rust removal apply equally in both cases; the same methods of surface preparation are worth while.

The present prices of high-tensile steels represent a premium of about 15–20% over structural mild steel, which corresponds approximately with the weight saving that could be expected in ordinary building applications. The field of application of such steels may, therefore, be restricted to special structures, such as long-span bridges, and to cranes and jibs, where deadweight reduction has intrinsic advantages. These low-alloy, high-tensile steels (*e.g.*, B.S. 548 and 968), however, are at least 20% more corrosion resistant than ordinary mild steel, so that the behaviour of lighter sections in the course of time is balanced on this account.

The Fourth Report of the Steel Economy Committee[7] states that "the increased use of high-tensile steel in general building may be a slow and continuous development. In its other applications progress will depend upon the extent to which economic factors begin to tell, such as lower capital cost, reduced operating costs or, in the transport industries, increased pay-load capacity."

ECONOMIC COMPARISON OF METHODS OF SURFACE PREPARATION

Dr. Hudson has already referred to the importance of the initial surface condition of the steel on the life

Table IV
FLAME-CLEANING COSTS

Date when Work Performed	No. of Structures Involved	Range of Cost Per Sq. Yd.	Average Cost/Sq. Yd. (approx.)	Remarks
Before June, 1946	12	4*s.* to 9*s.*	6*s.*	Not including overheads and profits
Early 1947	1	...	6*s.* 3*d.*	Including overheads and profits
Before Sept., 1948	18	1*s.* to 12*s.*	6*s.* 6*d.*	Believed not including overheads and profits
...	Numerous	...	9*s.*	Walsh[8]

of the paint and he has given some indication of the several methods of surface preparation. All methods which result in a surface free from rust and scale are comparable in that they provide a good surface for the application of paint. The choice of any particular method will be governed largely by economic factors, and some consideration of these for the various methods is now given.

Flame-Cleaning

Flame-cleaning will satisfactorily clean weathered, unpainted steel, but it will not remove firmly bonded millscale from freshly rolled steel. When reconditioning existing structures the average labour charges account for about 40% of the total cost of flame-cleaning and at the present time it seems quite possible that 7*s.* 6*d.*–9*s.* 0*d.* per sq. yd. (or 10*d.*–1*s.* 0*d.* per sq. ft.) is a reasonable average figure for the overall cost. Collected cost data given in Table IV show the wide variation in cost and also the high average intrinsic cost of such rectification. Flame-cleaning does not lend itself readily to mechanization, which would be one way of lowering its cost. The necessity for thorough wire-brushing subsequent to the passage of the flame over the steel also lessens the attractiveness of this process.

An interesting practical note—and word of caution—is sounded by Rigby[9] who states : " Experience has shown . . . there is often an appreciable difference in costs even between identical structures with a similar degree of corrosion. . . . The human element plays a prominent part in determining the costs of the flame-cleaning process. . . . The process is not inexpensive and the greatest care should be exercised to avoid unnecessary consumption of gases. Moreover, in the absence of supervision, operators may have a widely different conception of a properly cleaned surface. Departure from recommended gas pressures may also give rise to appreciable differences in total costs. It will therefore be appreciated that on this account alone, not every figure recorded today has been truly representative of the actual cost of flame cleaning."

Sand- and Gritblasting

Compressed-air sand- and gritblasting by hand methods tend to be somewhat cheaper than flame-cleaning, especially for cleaning ' new ' steel, and they are rather more effective. The main difficulty, when the processes are used on site, is the recovery of the abrasive, and sand is therefore used where possible. A hand-operated machine, known as the Vacu-Blaster (Fig. 8), which automatically recovers the abrasive and dust, has recently been introduced in this country. Data supplied by the makers indicate that the use of this machine will be at least competitive with conventional hand-operated blasting equipment. The machine should be particularly attractive for re-touching localized coating damage (*see* p. 177).

Mechanized gritblasting by wheelabrators, the principle of which is depicted in Fig. 9, costs only a fraction of hand methods in spite of the high capital cost of the wheelabrators. A well-designed machine for the mass treatment of sections (on the lines of Fig. 10 which shows angle sections being cleaned) might clean an average scaled surface for 1½*d.*/sq. ft. or even less. A machine of this type has now been in operation for over two years and will clean five

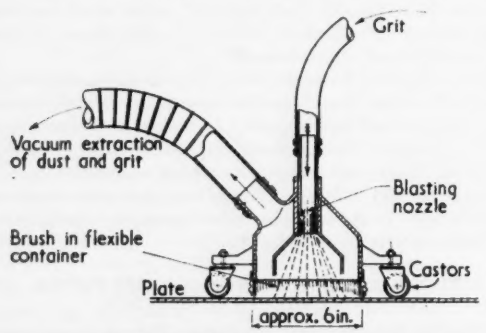

Fig. 8—The Vacu-Blaster

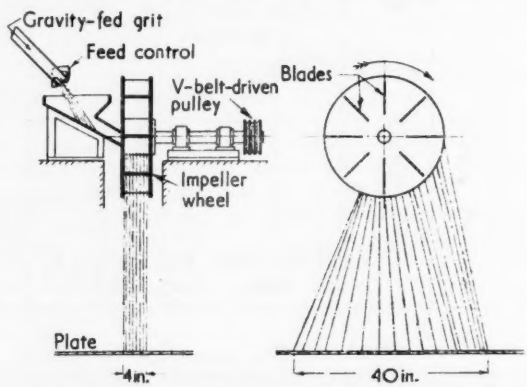

Fig. 9—Principle of the Tilghman wheelabrator

3 in. × 3 in. angles at 3–4 ft./min. or two 12 in. × 5 in. joists at half this speed (average of 15–20 sq. ft./min.). The length of the work, which can be treated by this method, is not limited by the machine itself but by handling facilities.

It is imperative that the consumption of the abrasive should be kept to a minimum otherwise its cost will become an appreciable item. The abrasive used is angular grit (crushed chilled-iron shot), often wrongly referred to as steel grit. In the machine illustrated, the grit is reclaimed from the hopper and conveyed to separators, where the scale, dirt, and broken grit, etc., are removed and the good grit is recirculated to the impellers. The choice of size of grit depends on the nature of the surface to be cleaned and on the coating subsequently to be applied and on other factors such as the impeller speed, although the latter will usually be fixed in a particular machine.

For subsequent metal spraying the bond will be improved by using larger grit, but unfortunately the speed of the operation will be lower. The smallest

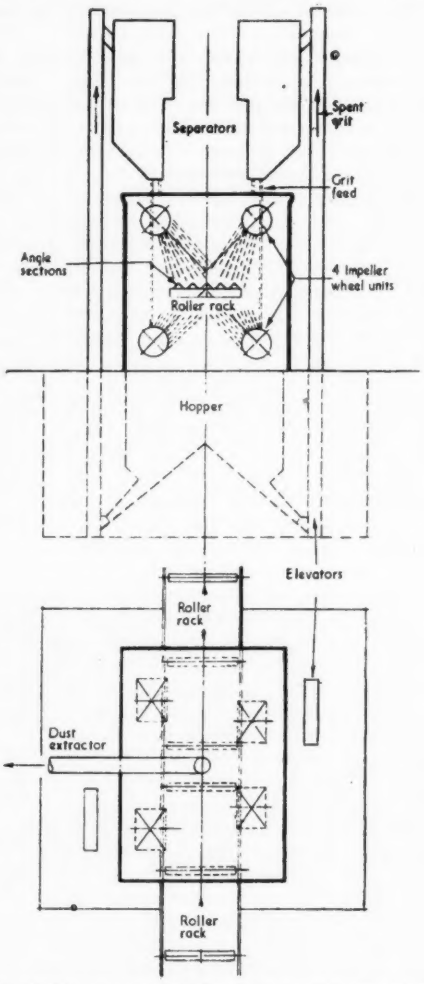

Fig. 10—Diagram of a gritblasting machine for cleaning sections

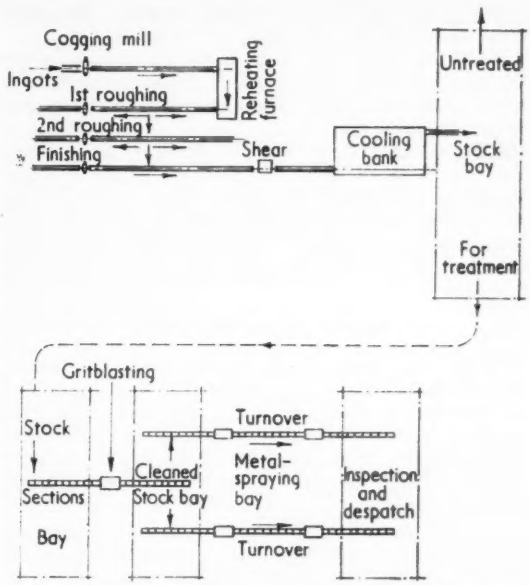

Fig. 11—Suggested flow of sections from the rolling mill through gritblasting and metal-spraying plant

grit that will give a good bond should therefore be employed. The grade of grit and speed of operation, in a set-up as suggested in Fig. 11 can, however, only be chosen to suit the worst surface condition. With air-blasting, excessive air pressures tend to cause a high rate of grit breakdown.

Experiments with a new type of shot, manufactured by cutting $\frac{1}{32}$-in. dia. high-tensile wire into $\frac{1}{32}$-in. pieces, have been carried out. The tendency of this material to break-down is considerably less than that of ordinary angular grit and it causes less wear and tear on the wheelabrator mechanism, which more than justifies its high cost. Unfortunately, it rapidly tends to become 'spherical,' which limits its useful life as an abrasive.

A deposit of fine iron dust may occur on a grit-blasted surface, and this should be removed before further treatment.

Pickling

As pickling is frequently associated with a final dip in 2% phosphoric acid, which has a mild phosphating action, the process involves a series of tanks containing the pickling acid, an alkali or water wash, and the phosphoric acid solution. The pickling acid can be cold hydrochloric, hot sulphuric, or hot phosphoric (of much higher concentration than for the mild phosphating action already referred to). Phosphoric acid is rather expensive, and the tendency is to use 5% sulphuric acid at 60–65° C. The water wash takes place at the same temperature, and the phosphating dip at 80–85° C. Bath temperatures are maintained by steam heating—the process is therefore dependent upon the availability of the necessary quantity of steam. Other requirements are acid storage and pumping equipment, and acid disposal facilities. The process is essentially batch-type, the

stock being handled by overhead cranes. The cycle time, including phosphating, is about ½ hr.

The ' phosphoric pickling ' of steel plates and some sections has been carried out to a limited extent by steel fabricators, apart from galvanizers and motor body builders, for many years. The process is distinctly competitive with mechanized gritblasting and has been of particular interest to the gas and chemical industries, the plates and sections being fabricated, pickled, and whilst still warm are paintep with a selected primer. The materials are shipped, transported to site, and erected, and then finally painted.

PROTECTIVE SCHEMES

With any method of cleaning, even on mildly phosphated surfaces, it is essential to apply some sort of protection with the minimum delay otherwise rusting will occur. The cleaning and protective processes should therefore be integrated where practicable. These processes can be effected at one of the following stages :

(i) Material totally treated before any machining or fabricating operation, *i.e.*, in as-rolled lengths (adjacent to the rolling mill)
(ii) Material cut to length, drilled, and then totally treated at the fabricators' works
(iii) Material cut, drilled, bent, and welded or riveted and assembled into transportable units and then totally treated
(iv) Structure treated after erection on site.

Protection applied at stage (i) (and to a lesser extent also at stage (ii)) must comply with the following conditions :

(1) The cost of a coating film shall not be excessive
(2) It must be cheap to apply
(3) It must offer no obstacles during processes of fabrication
(4) In particular, it must be possible to weld through it
(5) It must not be over-sensitive to the type of damage that would result from drilling, shearing, etc., during fabrication, and from scratching and bruising during the erection processes
(6) It must be possible to patch such damage as might result, in a reasonably effective and cheap manner
(7) The coating, after exposure for a period of up to 12 months, must form a suitable basis, without further preparation or removal, for the application of the final painting scheme.

The sixth condition must be considered in relation to all the four different stages at which the protective treatment can be applied, as the incremental cost incurred by ' touching-up ' damage, etc., must be taken into account in the overall assessment (*see* p. 177).

There are, of course, many processes which aim at (and doubtless accomplish) a high degree of protection of larger or smaller elements of steelwork—such as hot-tinning, anodizing, phosphating (by proprietary processes such as Bonderizing and Parkerizing, etc. as distinct from the mild phosphating produced by dipping in hot phosphoric acid), and other processes involving the use of plastics and resins ; these in the main relate to smaller articles and the process is applied after fabrication. There are three main types of coating—paint, rust-preventive oil (linseed oil), and metallic coatings. The application of paint has been adequately dealt with in Part I of this paper. Linseed oil would go a long way towards satisfying the seven requirements, provided there is thorough supervision to ensure continuous coating, but it is at present expensive and in short supply. There is clearly a case for developing a rust-preventive oil that would be satisfactory for use at stage (i), and in fact there are a number of dewatering fluids and the like already on the market, but they do not seem eminently suitable for structural steel owing to their inability to satisfy simultaneously more than two or three of the seven conditions specified.

Metallic Coatings

The production of metallic coatings by cementation methods are not practicable for structural steel. Electrodeposition methods can generally be dismissed as too costly, although it is believed that electrodeposited lead coatings were used on some German State Railway bridges before the war. One is left with the choice of either hot-dipping or metal-spraying.

Hot-Dipping—Galvanized coatings, which have been produced by hot-dipping for many years, are usually preceded by pickling, but other methods of descaling may be suitable. The cost of galvanizing structural steel is at present very high, partly because there is not sufficient demand to justify large-scale galvanizing plant, and partly because cost systems in the trade are usually founded, to some extent, on a weight basis. For this reason it is difficult to assess a truly representative cost per sq. ft. of surface treated, but for comparable coatings it is unlikely that galvanizing will be cheaper than other methods.

Numerous attempts have been made to produce aluminium coatings by a hot-dipping process but it appears that considerable difficulty is experienced because of the rapid growth of a thick alloy layer when using a pure aluminium bath. By the addition of about 5% of silicon to the bath, thin ductile coatings are being produced in the U.S.A. A method of producing aluminium hot-dipped coatings, which involves preheating the steel sheet in a controlled atmosphere before it enters the aluminium bath, has been developed by the Armco Steel Corporation for the manufacture of aluminized steel sheets on a commercial basis.[10] The necessity for this preheating procedure would make its inclusion in a structural steel production line somewhat impracticable. At the present time, therefore, hot-dipped aluminium coatings do not appear to present a serious challenge to coatings produced by established methods.

Dipping processes are restricted by the overall bath dimensions and the weight of coating metal in the bath. Within limits these processes can thus be effected at stage (iii), probably at a slightly higher cost than at stages (i) or (ii) because of more difficult handling, etc. Also, where acids are involved, great care must be taken to avoid leaving acid in crevices.

Metal-Spraying—In its simplest form metal-spraying is a hand process, for which several makes of spraying pistol are available, some for spraying wire and others for spraying powdered metals : there is also a third method in which molten metal is sprayed.

The two former methods require oxygen and a fuel gas to melt the wire or powder. Compressed air is required in the wire/powder feeding mechanisms and for propelling the molten particles to the stock. Some wire pistols, designed for use on mountings, incorporate electrically driven wire feeds.

Metal-spraying can only be applied successfully to gritblasted surfaces. Hand-cleaned and sprayed work (3 mils of aluminium or zinc) might cost 9*d*. to 2*s*. 6*d*., or even more, per sq. ft., depending upon the nature of the work. Owing to the relative densities and costs of the two metals, zinc-spraying will always cost a little more than aluminium-spraying. Other metals can be sprayed but are more expensive and/or offer less protection than aluminium or zinc.

Unlike pickling and hot-dipping processes, gritblasting and metal-spraying can be carried out at stage (iv).

The reduced cost of mechanized treatment procedure, already illustrated in relation to gritblasting, applies equally well to metal-spraying. There is a further advantage in the control of coating thickness facilitated by mechanization. A successful mechanical plant for spraying sections is shown in Fig. 12. This machine mounts up to 28 nozzles, depending on the size and shape of sections being sprayed. The sections pass through the machine on a constant-speed conveyor, and the coverage rate thus varies considerably. The plant is restricted to lengths of material of constant cross-section. For economical metal-spraying, therefore, the steel must be in simple bar form, and a cost figure of 3*d*. to 3½*d*. per sq. ft. for a 3-mils aluminium coating (including gritblasting) seems possible. Such mechanized treatment is, of course, confined to stages (i) and (ii).

Fabrication Considerations

Interference with fabrication processes by protective coatings is an important feature. Toxic fumes limit the use of lead paints where gas-cutting or welding processes are concerned, unless the paint is removed by suitable solvents. Toxic fumes have also been reported from chromate primers.[11] No difficulties appear to arise when lightly phosphated steels are welded. Tests suggest that no difficulty should be encountered in welding through zinc coatings ; both cutting and welding through aluminium coatings are now practicable.

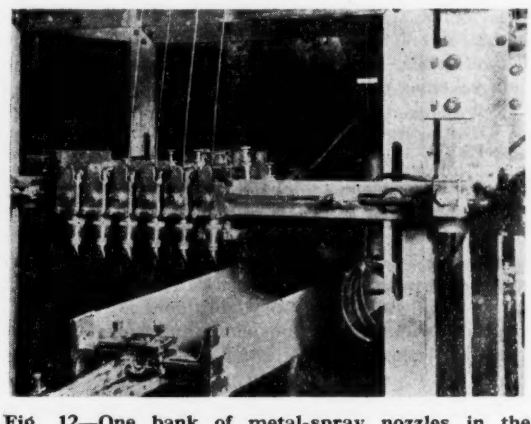

Fig. 12—One bank of metal-spray nozzles in the mechanized unit

Economic Factors

In the overall appreciation of the relative merits of effecting treatment at each of the four stages both the initial treatment cost and the cost of rectifying the damage to the coating, etc., to obtain sound protection, must be considered.

Initial treatment at stage (i) will be the cheapest (assuming full mechanization where practicable), but this stage involves the maximum amount of touching-up on site, or after fabrication, because of cut ends, rivet heads, welds, and damage. On the other hand it ensures that the interfaces are fully protected, except for the insides of rivet holes, which are considered not to matter.

Initial treatment at stage (ii) will cost more than at stage (i) because of more individual handling per ton throughout. The cleaning process may be more difficult if the steel has become heavily rusted while in stock, but there is a 100% yield of treated material. Touching-up of rivet heads and welds is required as at stage (i) but there is less touching-up of damage and cut ends. Interfaces are fully protected and possibly also the rivet holes.

The cost at stage (iii) depends on whether hand methods are needed, but will most certainly be more expensive than at earlier stages even with dipping methods, owing to the heavier units to be treated. Only a little touching-up on site is involved (*e.g.*, transit and erection damage) but the interfaces have no adequate surface preparation beyond conventional wirebrushing and priming, whilst built-up members tend to make certain parts inaccessible for cleaning, etc., with hand-operated equipment.

Stage (iv) will incur the greatest initial cost although in many cases it will be possible to apply the priming paint immediately to the cleaned surface without the use of a metallic coating. There is no touching-up, and interfaces are in the same condition as at stage (iii). But difficulties caused by inaccessibility are likely to be aggravated.

It is assumed that all protective schemes will include painting after erection, the aim of the initial surface preparation being to prolong the life of the paint. In the initial stages it is reasonable to say that a metallic coating can replace at least one coat of a normal multi-coat painting scheme, but this does not apply to pickled and mildly phosphated work.

Rectification of Damage—The magnitude of the touching-up costs in any protective scheme can be minimized by doing as much as possible of this retouching in the fabricators' works, *e.g.*, on rivet heads and welds. Obviously the only scheme which can be rectified by the processes originally applied, is gritblasting and metal-spraying and, depending on the nature of the structure and the extent of the rectification required, this may involve as much as an additional 2*d*./sq. ft., based on the total structural area. It is here that the Vacu-Blaster may prove invaluable, but less elaborate methods could be used to good effect at about half the above cost. For instance, wirebrushing and spot-priming, with suit-

able paints, all welds, rivet heads, etc., shortly after fixing in position in the fabricators' works, will not only reduce the cost of the work, but, if carried out thoroughly, will afford the paint a good chance of completely fulfilling its purpose. The touching-up work still to be done on site will be in connection with site welding, riveting, or bolting and with repairs to coating damage incurred in transit and erection. The former category can be dealt with in the same way as in the fabricating shop and with equal effect, but the latter category may be less effective because of incipient rusting, although by virtue of its nature and location it will probably be less critical in its effect.

Overall Initial Costs—At stage (i) a pickling and mild-phosphating scheme would probably cost 1½*d.*/sq. ft. more, and mechanized gritblasting and metal-spraying 2*d.* to 2½*d.*/sq. ft. more, than the typical present-day practice of weathering, wirebrushing, and priming, allowing for a moderate amount of touching-up. Pickling and galvanizing would probably be still more expensive. It is not easy to assess the appropriate figures at stage (ii), but at stages (iii) and (iv) they would probably be several times those at stage (i).

The amount of rectification, which is economically justified, requires careful consideration. If corrosive conditions were severe all damage would have to be very thoroughly repaired. Under more normal conditions and where there is a balance between the preservation and the appearance of the steel, a damaged coating less thoroughly repaired may not greatly reduce the repainting period that might be achieved under ideal conditions : whilst the damaged areas may be slightly rusty, the rust would not present the same threat of failure to paint life as would scale. Also, local paint failure, which might arise, would not spread beneath the paint film and lead to large areas of failure, since a metal coating, at any rate, will confine damage and prevent its spread. However, it is essential that in all cases the savings achieved by bulk processing shall exceed by a substantial margin the additional cost of making good such damage as arises.

There will be circumstances where cleaning and priming treatment at stages (i) or (ii) will have an advantage over treatment at a later stage. There may also be instances where the effects of fabrication are so extensive that subsequent treatment is more appropriate.

MAINTENANCE OF STRUCTURES

Repainting Interval

It is not easy to decide when repainting is economically desirable, as the assessment must take into account not only the damage already suffered but also the anticipated rate of deterioration if the repainting is delayed. If no rust has yet appeared, one hesitates to repaint, whilst if any appreciable amount of rust is present the whole repainting procedure becomes more difficult and costly. For this reason, repainting programmes are difficult to incorporate in a planned maintenance scheme, but in such cases it would probably prove judicious to secure a margin of safety by repainting at shorter intervals than the maximum estimated paint life. Where thorough surface preparation has been carried out a more uniform paint life might be expected, making possible a more precise assessment of the desirable repainting period, and furthermore it reduces the consequence of a fortuitous delay in repainting.

The Joint Technical Panel J/P1 consider that under practical conditions it is desirable to repaint structures when between 0·2% and 0·5% rusting (not including rust staining) has been reached. An impression of such rusting, on surfaces prepared for painting by weathering and wirebrushing, is given by a series of natural-size photographs, recently published by the British Iron and Steel Research Association,[12] showing ' standard degrees of rusting.' These, or similar photographs for other initial conditions, may be of assistance to maintenance engineers and others in assessing the break-down of paint on steel structures. Even so, there is no practical measure of the degree of rusting and although the photographs can be used as ' comparators,' the human element can give rise to varied decisions. If conditions are such that paint failure occurs sporadically, local repainting might be worth while but would not necessarily be cheaper in the long run, especially if scaffolding is required.

ECONOMIC JUSTIFICATION OF INCREASED EXPENDITURE ON PROTECTIVE MEASURES

The expenditure incurred by the surface preparation and retouching procedures can be justified only by the increased life of the paint so obtained and the consequent reduction in maintenance costs. Surfaces, which have been thoroughly prepared before initial painting, will generally require less cleaning down and repriming and will therefore be easier and cheaper to repaint than unprepared surfaces.

It is not easy to convince those concerned with large capital expenditure of the value of a higher initial investment for the sake of future benefits, but to this end, when estimating the extent and cost of maintenance likely to be required during the useful life of a certain structure, the effects of variations in present-day costs should be considered. Labour charges account for the major part of protective maintenance costs and therefore higher initial capital expenditure on measures, which will reduce the amount of maintenance subsequently required, are in the end more economical.

Evidence from many exposure tests suggests that under average industrial conditions, the period between successive repaintings over different preparation schemes might be of the following order :

Weathered and wire-brushed, 3 yr. (2·5)
Flame-cleaned and primed at works, 5 yr. (1·75)
Pickled and phosphoric acid dipped and immediately primed, 5½ yr. (1·25)
Gritblasted and metal-sprayed (3 mils), 7 yr. (1·0)

Summation of the costs of preparation at stage (i) together with painting and repainting a structure over a period of 50 years gives relative totals, which are shown in brackets. Whilst these figures may not apply in all cases, they probably hold for structures exposed to industrial atmospheres and where aesthetic considerations are not of great importance.

PRACTICAL EXAMPLES

From a consideration of the factors discussed in the preceding paragraphs it was decided to aluminium-

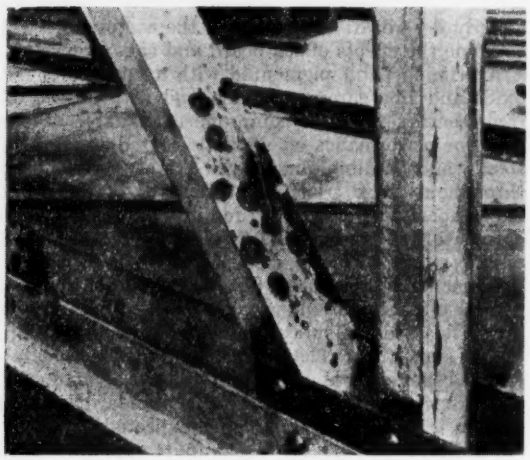

Fig. 13—Part of an E.O.T. crane girder constructed from aluminium-sprayed steel

spray all the steelwork above crane-track level in various shops of the new works of the Steel Company of Wales at Margam. In the main the gritblasting and aluminium-spraying were carried out at stage (ii). It was decided to spray only the steelwork above crane-track level because the stanchions and crane runways were too large to be handled by available mechanized plant, and because there was very extensive site welding to be carried out : subsequent research, however, has proved that welding through aluminium-coated steel (up to a 5-mils coating thickness) presents no insuperable difficulty. The lower portion of the building is also reasonably accessible for repainting and maintenance and does not greatly affect the lighting of the shop. The steelwork above the crane-track level, however, has a profound effect upon the natural lighting, and would be difficult and costly to repaint, as any scaffolding would interfere with continuous operations.

Several trials are at present in progress within The United Steel Companies. One trial consists of two treatments applied to the steel of the main structural components and end carriages of a series of 10-ton, 80-ft. span E.O.T. cranes now in service in an exposed steel scrapyard. A 'control' is provided by one crane constructed from partly weathered steel and given one coat of paint after fabrication (before delivery to the site), thus representing normal present-day practice. The two surface treatments were applied at stage (i) and consisted of (*a*) gritblasting followed by an immediate coat of paint, and (*b*) gritblasting followed by spraying with 3–4 mils of aluminium. The cranes built from these materials were also painted with one coat before delivery to the site.

Much welding, which was carried out without difficulty, was involved on the end carriages, and consequently an abnormal amount of touching-up of welds, cut edges, etc., was necessary. The retouching of these and all other 'defects' consisted of chipping and/or thorough wirebrushing. The coating damage, both to the paint and aluminium, was surprisingly slight, but where machining operations involving the application of coolants and oil were performed, the resultant contamination of the metal-sprayed coating was somewhat displeasing and the oil was difficult to remove owing to the porosity of the coating. An example of this type of contamination is shown in Fig. 13, which also shows other dirty marks inherent in the general handling of the sections. The dark areas on and around the gusset plates are priming paint applied to mating surfaces. Normally such priming would not be considered necessary with aluminium-sprayed sections. A difficulty, which was rather more serious than was anticipated, was encountered in flame-cutting the aluminium-sprayed steel. The speed of cutting was reduced by about 50%. It is now known that a powder-cutting method can be used which is faster and also reasonably competitive with ordinary methods used for mild steel.

Since only about half the painted area of a complete crane was treated, the cost of gritblasting and prime-painting increased the crane cost by just over 1%, and gritblasting and aluminium-spraying by about $1\frac{3}{4}$%, compared with the normal cost, if the extra transport and handling costs incurred by sending the steelwork for treatment are excluded. These figures do not include subsequent painting. They are considerably higher than might be possible if a fully developed gritblasting and metal-spraying plant were available. Painting costs per coat for a complete crane represent about $\frac{1}{2}$% of the total crane cost.

A second trial, of wider scope, comprises a series of 20-ton wagon underframes for internal steelworks use, embracing six different protective schemes plus a

Table V

DETAILS OF SURFACE PREPARATION AND PROTECTION APPLIED TO WAGON UNDERFRAMES

Treatment	Stage	No. of Coats of Paint Applied at Stage (iv)	Relative Costs
(*a*) Weathering and wire-brushing (control)	(iv)	2	1
(*b*) Flame-cleaning and immediate prime-painting	(iv)	1	$2\frac{1}{2}$
(*c*) Gritblasting—no immediate protection	(i)	2	
(*d*) Gritblasting and immediate prime-painting	(i)	1	$1\frac{3}{4}$
(*e*) Gritblasting and 3–4 mils sprayed aluminium (mechanized application)	(i)	1	$2\frac{7}{4}$
(*f*) Ditto, plus retouching by the same processes	(i) (iii)	1	$3\frac{3}{4}$
(*g*) Gritblasting plus 3–4 mils sprayed aluminium (hand application)	(iii)	1	$4\frac{1}{2}$

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'control' representing present practice. The treatments are specified in Table V. In this case at stage (iii) the underframes only were concerned, whilst at stage (iv) the wagon bodies had been fitted : at all stages the underframes could be handled. Consequently, the costs given in the last column of the Table are subject to modification before they can be applied as a guide for structures where scaffolding would be required. Also, these costs are not directly comparable within themselves, since the application of the first coats of paint was carried out at three different places, at quite widely varying costs, and whereas the cost of flame-cleaning on an average structure would be higher than for these wagon underframes, the cost of gritblasting and metal-spraying for work at stage (i) was high, as for the E.O.T. cranes. The high cost of thorough touching-up is emphasized and in an average structure might be rather higher than here, since these structures were small enough to be brought to the touching-up plant—a perhaps unusual circumstance.

The surfaces treated by method (*c*) (Table V) were thoroughly rusted by the time fabrication commenced. Some of the aluminium-sprayed steel became very dirty while in stock (about four months) and further contamination with dirt and oil occurred during fabrication, but damage to the coating was not considered significant. No fabrication difficulties were reported but, because of the relative inaccessibility of some parts of the underframes, flame-cleaning was troublesome. This applies, although to a less extent, to metal-spraying.

A third trial on the steelwork of a small lean-to shed, which covers steam and water service pipes and valves is showing the advantages of surface preparation after only 12 months' service. The corrosive conditions inside this shed are particularly severe because, except for a few hours each weekend, a dense cloud of steam arises from a culvert in one corner of the shed and, because of condensation, all the internal surfaces of the building are virtually immersed in water. Structural members, which received only normal treatment, are rusting badly, whereas members which were gritblasted and aluminium-sprayed at stage (i) are showing no signs of rusting, although sporadic paint failure is occurring, most probably due to an unfortunate choice of paint for these particular conditions.

A further trial on a coal stockpile structure is planned on similar lines to that on the E.O.T. cranes already described. In this trial the atmosphere will combine the effects of sea-board and coke ovens.

A priming paint pigmented with a mixture of red oxide and zinc chromate and bound with linseed oil (representing the best compromise available at the time for performance on millscale-coated steel, rusty steel, and aluminium-sprayed steel) was used throughout these trials as a standard of reference. Its composition[13] was : 53% red iron oxide, 16% zinc chromate, 13% refined linseed oil, 13% boiled linseed oil, 2% white spirit, 3% driers.

Elementary structures, *i.e.*, 'bus shelters, are now available in aluminium-sprayed steel. Such shelters are gritblasted and sprayed by hand after fabrication, *i.e.*, at stage (iii). The extra charge for these metal-sprayed shelters, which (unpainted) have an attractive appearance, as compared with a standard painted shelter is approx. 30%. It is expected that this expenditure will be recovered in terms of reduced maintenance well before the shelters have served their useful lives.

CONCLUSIONS

The scientific view that positive achievement can accrue from proper surface preparation and treatment of new exposed structural steelwork erected in industrial atmospheres is supported by a growing amount of practical evidence. The stage at which this is carried out may vary from bulk treatment shortly after rolling, to treatment only after completion of erection. The former permits a high degree of mechanization but involves hand rectification at a later stage, whilst the latter involves the use of hand tools throughout. A balance of these considerations will control the practice adopted in individual cases : but it has been shown that the mechanized treatment of an as-rolled section may be only a fraction of the cost of treatment at a later stage.

The method of cleaning and the protective coating chosen will vary with circumstances, *e.g.*, with conditions of service, expected life of the structure, and with maintenance facilities.

Acknowledgments

The author thanks the Director of Research of The United Steel Companies, Ltd., for permission to publish this paper ; also Vacu-Blast, Ltd., Tilghman's Patent Sand Blast Co., Ltd., Metallisation, Ltd., the British Iron and Steel Research Association, and The Steel Company of Wales, Ltd., for their co-operation in supplying information and illustrations.

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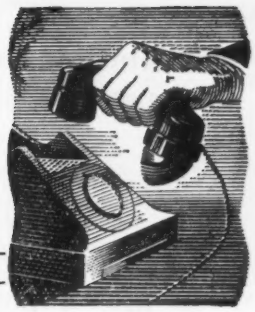

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

President

At the Annual General Meeting of the Institute, held on 30th May–1st June, Mr. Richard Mather, Chairman and Managing Director of the Skinningrove Iron Co., Ltd., was inducted as President for the session 1951–52 by the retiring President, Mr. J. R. Menzies-Wilson. Biographical notes and a portrait of Mr. Mather form the frontispiece to this issue of the *Journal*.

Meetings

Special Meeting in Austria

Details of the Special Meeting in Austria, to be held from **5th–19th September, 1951** were given in the February and May issues of the *Journal*.

Autumn General Meeting

The Autumn General Meeting of the Institute will be held in London on **21st–22nd November, 1951.**

Williams Prize

The Williams Prize Fund originated from the presentation of a sum of £3000 by Mr. Illtyd Williams on his retirement from the Honorary Treasurership of the Institute in 1926.

The interest from the fund is devoted to the making of an award to the author or authors of a paper of a practical character adjudged by the Council to be the best paper of that character published in the *Journal*. The award is made only to authors who are British subjects regularly employed in a British iron or steel works and employed, at the time of presenting the paper, in a position not superior to that of manager of any one technical department.

In connection with the award of the Prize in 1950, to Mr. T. H. Harris and Mr. W. H. Everard, it is pointed out that the third author of the paper, Mr. D. J. O. Brandt, is not eligible to receive the Prize, since he is a member of the staff of the British Iron and Steel Research Association. The Council have expressed their appreciation to Mr. Brandt for his share of the work.

The Worshipful Company of Blacksmiths

In accordance with an understanding with the Prime Warden and Wardens of the Worshipful Company of Blacksmiths, the Council of The Iron and Steel Institute has the privilege of putting forward each year two applications for nomination for admission to the Company at reduced fees. Applicants must be British subjects and Members of the Institute. The reduced fees are as follows :

Freedom Fine	£6	0	0
Livery Fine	£22	0	0
Steward's Fine	£21	10	0
Clerk's Fee	£1	12	6
Beadle's Fee		15	0
	£51	17	6

Any Member of The Iron and Steel Institute wishing to avail himself of these concessions should ask the Secretary to submit his name to the Wardens of the Company.

S. J. Kennett

In the biography of Dr. Kennett, published as the frontispiece to the April issue of the *Journal*, the omission of part of a sentence has given the impression that Professor C. O. Bannister is dead. The second line of the second paragraph should read : " Liverpool University, under the late Professor of Metallurgy, Dr. C. O. Bannister. He became Lecturer "

We express our apologies to Dr. Bannister for any inconvenience this error may have caused.

Marriage of K. Headlam-Morley

The marriage arranged between Mr. Kenneth Headlam-Morley, Secretary of The Iron and Steel Institute, and Miss Lorna Kinchin Smith will take place at St. Margaret's Church, Westminster, on Saturday, 9th June, 1951.

NEWS OF MEMBERS

▶ Mr. A. G. DUCE has received the M.A. degree of the University of Cambridge.

▶ Dr. P. HERASYMENKO has left The United Steel Companies, Ltd., Stocksbridge, to take up residence in the United States.

▶ Mr. H. HUMPHRIES has been appointed Deputy Chairman and Managing Director of Hadfields Ltd., East Hecla Works, Sheffield, in succession to Mr. J. B. Thomas. It is regretted that this was incorrectly reported in the March, 1951, issue of the *Journal*.

▶ Mr. H. LEE has been awarded the degree of Doctor of Metallurgy by the University of Sheffield.

▶ Mr. J. S. MAYNE has received the Premier Award of the Junior Institution of Engineers for a paper on " Mechanical Aids in the Operation of Rolling Mills."

▶ Mr. G. C. E. OLDS has been elected a Graduate of the Institution of Mechanical Engineers.

▶ Mr. F. L. PARKIN has resigned his position as Chief Electrical Engineer to Messrs. Steel, Peech and Tozer, to take up an appointment as General Manager, Messrs. Aerex Ltd., Sheffield.

▶ Dr. E. C. ROLLASON has been appointed Professor of Metallurgy at Liverpool University and is relinquishing his present position of Director and Research Manager at Murex Welding Processes Ltd., on September 28th, 1951.

▶ Mr. R. W. STOBBS, formerly Chief Metallurgist with J. and H. McLaren, Ltd., and Bryce Fuel Injection, Ltd., has been appointed Senior Research Metallurgist with the David Brown Foundries Company, Penistone.

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CONTRIBUTORS TO THE JOURNAL

T. W. Lomas, B.Sc.—Member of the research staff of Hadfields Ltd., Sheffield. Mr. Lomas obtained the B.Sc.(Hons.) degree of Sheffield University in 1947. His university course was interrupted during the war by a period at the Signals Research and Development Establishment, where he specialized in telecommunications. He took up his present position in 1947 and is in charge of the electronic equipment of the research department.

THE IRON AND STEEL ENGINEERS GROUP

The **Fifteenth Meeting** of the Iron and Steel Engineers Group will be held at 4 Grosvenor Gardens, London, S.W.1, on **Tuesday, 19th June, 1951.**

The Morning Session, commencing at 10.30 A.M., will be devoted to the discussion of the paper "*Protection of Structural Steel Against Atmospheric Corrosion*," by J. C. Hudson and W. A. Johnson (this issue). The Afternoon Session, commencing at 2.0 P.M., will be open for a discussion on "Mechanical Handling," to be introduced by members of the Productivity Team on this subject who recently visited the U.S.A.

Engineering Committee, 1951–52

The following members have been appointed to serve on the Engineering Committee :

Chairman

Mr. C. H. T. WILLIAMS	Park Gate Iron and Steel Co., Ltd.

Members

Mr. J. BAKER	Jos. Booth Bros., Ltd.
Mr. J. L. GASKELL	Appleby-Frodingham Steel Co., Ltd.
Mr. T. A. HOGARTH	Llanelly Steel Co. (1907) Ltd.
Mr. W. M. LARKE	Stewarts and Lloyds, Bilston
Mr. P. A. LEE	Arthur Lee and Sons, Ltd.
Mr. G. S. MARTIN	Lanarkshire Steel Co., Ltd.
Mr. J. E. OWSTON	F. B. Engineers, Ltd.
Mr. W. J. POOL	British Thomson-Houston Co., Ltd.
Mr. A. TAYLOR	Cargo Fleet and South Durham Iron and Steel Co.
Mr. W. UDALL	Brightside Foundry and Engineering Co., Ltd.
Mr. R. L. WILLOTT	John Summers and Sons, Ltd.
Mr. P. WRIGHTSON	Head, Wrightson and Co., Ltd.

Ex-Officio

Mr. R. MATHER	President, The Iron and Steel Institute
Mr. J. MITCHELL, C.B.E.	Hon. Treasurer, The Iron and Steel Institute
Mr. H. H. MARDON	British Iron and Steel Research Association
Mr. I. S. SCOTT-MAXWELL	British Iron and Steel Federation

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

The Physical Society held an exhibition from 6th to 11th April at which the Association displayed four items. These were a thermocouple, in a protective sheath of alumina and silica, which is used for continuous temperature measurement in a side-blown converter ; an instrument for continuous measurement of the width of hot strip as it leaves the rolls at speeds up to 1800 feet per minute ; a system for continuously recording a number of measurements on one chart ; and a demonstration of a method for deducing the mean flame temperature and emissivity from measurements of the radiations from the flame.

MEMOIRS

George Glenn, a Past-President of the Sheffield Metallurgical Association, died on 1st March, 1951. He was educated at the Central Higher School, Sheffield, and took a four-year course in metallurgy at Sheffield University. For ten years he was senior assistant chemist with Messrs. Samuel Fox and Co., Ltd., Stocksbridge. He was successively senior assistant with Messrs. Jonas and Colver, Ltd., chief chemist and metallurgist with Messrs. Arthur Lee and Sons, Ltd., senior assistant at the Admiralty, Sheffield, and chief chemist and metallurgist with Tinsley Wire Industries, Ltd.

In 1920 he received the Sorby Prize of the Sheffield Metallurgical Association for a paper on cold-worked steels. He was a Founder Member of the Sheffield Metallurgical Association and was its President in 1943. In July 1950, on the occasion of his retirement from business, he was made an Honorary Member of the Association. He was elected a Member of The Iron and Steel Institute in 1918.

Harry Lund died on 22nd February, 1951, as a result of a motor cycle accident. He was born at Blackburn in 1924 and was educated at Balshaw's Grammar School, Leyland, and at Sheffield University, where he obtained the B.Sc. degree. He spent a short period with William Jessop and Sons, Sheffield, before joining the South-West Essex Technical College, where he obtained the M.Sc. degree in 1949. He joined the Department of Research and Technical Development, Messrs. Stewarts and Lloyds, Ltd., Corby, in May, 1949. Mr. Lund was elected a Member of The Iron and Steel Institute in 1945. He was an Associate of the Institute of Physics.

A. J. McFarland died on 28th November, 1950. He was born in Pennsylvania in 1883 and was educated at Spenciarian College, Cleveland, Ohio. He joined the Whitaker-Glessner Co. in 1905 and was later appointed general superintendent. After a year as general superintendent with the Wheeling Steel Corporation he held the same position with Follansbee Bros., West Virginia. In 1930 he was appointed an Executive Vice-President of the Wheeling Steel Corporation, Wheeling, West Virginia, and became President in 1941, a position which he held until 1950. Mr. McFarland became a Member of The Iron and Steel Institute in 1941. He was a member of the American Iron and Steel Institute, the Ohio Manufacturers' Association, and the Ohio Valley Board of Trade.

Leslie W. T. Webb, Casting Superintendent, I.C.I. Metals, Ltd., died on 25th February, 1951. After leaving school, Mr. Webb took a part-time course in pure science and metallurgy at Swansea Technical College and in 1938 he was awarded the City and Guilds prize and silver medal in non-ferrous metallurgy. He started work with I.C.I. Metals, Ltd., in 1933 and in 1941 he was appointed foreman of the light alloy factory and later became a technical assistant. In 1945 he was appointed Casting Superintendent. He was elected a Member of The Iron and Steel Institute in 1945 ; he was also a member of the Institute of Metals.

NEWS OF SCIENCE AND INDUSTRY

Mond Nickel Fellowships

The Mond Nickel Fellowships Committee invites applications for the award of Mond Nickel Fellowships for the year 1951. Awards will be made to selected applicants of British nationality, educated to University degree or similar standard, although not necessarily qualified in metallurgy, who wish to undergo a programme of training in industrial establishments; they will normally take the form of travelling Fellowships—awards for training at Universities may be made in special circumstances. There are no age limits although awards will seldom be given to persons over thirty-five years of age. Each Fellowship will occupy one full working year. The Committee hopes to award up to five Fellowships each year of an average value of £750 each.

Mond Nickel Fellowships will be awarded in furtherance of the following objects:

(*a*) To allow selected persons to pursue such training as will make them better capable of applying the results of research to the problems and processes of the British metallurgical and metal-using industries.

(*b*) To increase the number of persons who, if they are subsequently employed in executive and administrative positions in the British metallurgical and metal-using industries, will be competent to appreciate the technological significance of research and its results.

(*c*) To assist persons with qualifications in metallurgy to obtain additional training helpful in enabling them ultimately to assume executive and administrative positions in British metallurgical and metal-using industries.

(*d*) To provide training facilities whereby persons qualified in Sciences other than Metallurgy may be attracted into the metallurgical field and may help to alleviate the shortage of qualified metallurgists available to industry.

Applicants will be required to state the programme of training in respect of which they are applying for an award, as well as particulars of their education, qualifications, and previous career. Full particulars and forms of application may be obtained from The Secretary, Mond Nickel Fellowships Committee, 4 Grosvenor Gardens, London, S.W.1.

Joint Engineering Conference

On the occasion of the Festival of Britain, a Joint Engineering Conference will be held at the Institution of Civil Engineers, the Institution of Mechanical Engineers, and the Institution of Electrical Engineers, in London, from Monday, 4th June to Friday, 15th June, 1951. The Conference will be open to all members of the three Institutions and to members of the Institutions and Societies participating in the Conference of Commonwealth Engineering Institutions and the Conference of the Engineering Societies of Western Europe and the U.S.A. Members of these Institutions and Societies are cordially invited to attend and to take part in the discussions. Advance copies of the Papers will be available some time before the date of the conference.

The technical sessions will include papers on power (dealt with from the civil, mechanical, or electrical engineering viewpoint respectively, in three sessions), electrical measurements, lighting, mining, with a mechanical and electrical bias, and the mechanical engineering aspect of steelworks plant.

In addition to the technical sessions there will be a programme of visits to works and other places of interest on certain afternoons, opportunities to visit the 1951 Exhibition, and certain evening social functions. The attendance of ladies will be welcomed.

Scholarships in the U.S.A.

The Ministry of Education announces that, with the aim of contributing to industrial productivity in this country, 35 post-graduate scholarships will be awarded in 1951 for the study of technology and management at selected universities or technological institutes, and in industrial undertakings in the U.S.A. The cost of these awards will be met from funds provided by the American Economic Co-operation Administration.

Electron Microscopy Group of the Institute of Physics

The Committee of the Group has decided that a Conference shall be held on 19th–20th June, 1951, but that a Summer School should not be organized. Through the kindness of Professor J. F. Allen, the Department of Natural Philosophy, University of St. Andrews, is being made available for the meeting.

Engineering, Marine and Welding Exhibition

The next of this series of exhibitions is to be held at Olympia, London, W.14, from 30th August to 13th September, 1951.

As in previous years the Organizers have extended to all members of the Institute an invitation to visit the Exhibition. Requests for complimentary tickets should be made, as soon as possible, to the Secretary, 4 Grosvenor Gardens, London, S.W.1.

Physics of Solids

A Summer School on the Physics of Solids will be held in the H. H. Wills Physical Laboratory of the University of Bristol from Thursday, 6th September to Saturday, 15th September, 1951. The course will be similar in conception to those already held on the electrical and mechanical properties of solids. It is intended mainly for research students at universities and for members of staffs of Government and industrial laboratories who wish to familiarize themselves with the theoretical aspects of subjects with which they are concerned on the experimental side. The lectures will be by Professor N. F. Mott, Dr. F. C. Frank, Dr. D. Polder, and Dr. R. Hill, assisted by other members of the University.

Application forms, which should be completed by 1st July, and further particulars may be obtained from the Director of the Department of Adult Education, The University, Bristol, 8.

Building Research Congress

A comprehensive Congress on building research has been planned to take place from 11th to 20th September, 1951, at the Institution of Civil Engineers, London, S.W.1. The purpose of the Congress will be to review the progress made in research in relation to architecture, building, and the associated branches of civil engineering.

World Metallurgical Congress

The World Metallurgical Congress, sponsored by the American Society for Metals, will be held at Detroit, Michigan, U.S.A., from 15th October to 19th October, 1951, at the same time and in connection with the 33rd Annual National Metal Congress and National Metal Exposition.

It is intended that the Congress and Exposition shall provide an opportunity for conference at the top scientific level and for exchange of ideas among leading metal technologists and scientists, particularly from the ferrous

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and non-ferrous metal-producing and fabricating countries, as well as among representatives of metallurgical companies and organizations in those countries. Plant-inspection trips will precede the Congress.

Further information may be obtained from Mr. W. H. Eisenman, Secretary of the American Society for Metals, 7301, Euclid Avenue, Cleveland 3, Ohio, U.S.A.

Symposium on Abrasion and Wear

A two-day International Symposium on Abrasion and Wear, organized by Rubber-Stichting to celebrate the opening of its new building, will be held in November, 1951, at Delft. The first day of the Symposium will be devoted to the general aspects of abrasion and wear, including problems connected with friction and lubrication, and on the second day the abrasion and wear of metals, plastics, rubber, and other materials will be covered.

The organizing committee consists of Dr. R. Houwink, President, and Dr. H. C. J. de Decker, Secretary. Admittance will be free of charge and further particulars may be obtained from the Secretary, P.O. Box 66, Delft, Holland.

Electricity as an Aid to Productivity

A Report of the proceedings of the Conference on "Electricity as an Aid to Productivity" organized by the Utilization Section of the Institution of Electrical Engineers, which was held in November, 1950, is now available. The Report gives up-to-date information concerning the contribution that more factory electrification can make to the country's efforts towards increased production. Copies of the Report may be obtained, price 6*s*. per copy, post free, from the Secretary of The Institution of Electrical Engineers, Savoy Place, London, W.C.2.

Arc Welding Film

The Quasi-Arc Co., Ltd, Staffordshire, have completed a 16-mm. colour sound film covering various aspects of arc welding and the manufacture of arc welding electrodes and equipment. Copies of this film are available free of charge for showing to engineering societies, technical colleges, engineering training schools, and works' groups. Projectors and operators can be hired.

Non-Metallic Bearings

An annotated bibliography of 101 selected references on non-metallic bearings, ESL Bibliography No. 6, is available from the Engineering Societies' Library, 29 West 39th Street, New York 18, price $2.00.

Industrial Publications

▶ A representative range of chemical plant and processes covered by the Kestner Evaporator and Engineering Co., Ltd., is illustrated and briefly described in a new brochure, No. 282. A comprehensive range of leaflets giving detailed descriptions of the plants described in the brochure is also available.

▶ Continuous conveyor furnaces developed by Birlec, Ltd., are reviewed in a 15-page publication, No. 76. Furnaces are available for the continuous heat-treatment of heavy charges, rod, tube, sheets, strip, and wire components, nuts and bolts, and for treatments, such as gas carburizing, which require a stable atmosphere within the heating chamber.

The application of these Birlec furnaces for the heat-treatment of bearing races, and in the needle industry, are described in more detail in two reprints entitled "The Heat-Treatment of Bearing Races" and "Shaker-Hearth Furnaces in the Needle Industry," respectively.

▶ "Cochran Boilers Illustrated," issued by Cochran and Co., Annan, Ltd., shows, in pictures, some of the boiler installations and steam storage accumulators, representative of the Company products. The size of boiler, the working pressure, and normal output in pounds of steam per hour, are given.

▶ An illustrated booklet entitled "Scrap Means Steel" has been produced by Thos. W. Ward, Ltd., Sheffield, in support of the national scrap drive. It emphasizes the importance of scrap iron and steel in the country's steel-production programme. The booklet is aimed primarily at those industries that do not come into direct contact with steel production.

▶ Richard Thomas and Baldwins, Ltd., have issued a report comparing the performance of a new type of transformer core material, Anisotropic strip, with that of hot-rolled sheets. Figures and graphs are given which show that cores built from the cold-reduced Anisotropic grades, Alphasil 77, 66, and 55, are superior in watts-loss and have a very much smaller magnetizing current than the best hot-rolled sheets.

Changes of Address

THE TECHNICAL INFORMATION AND DOCUMENTS UNIT, which for a number of years has been attached to the Board of Trade, is now part of the Information Services of the Department of Scientific and Industrial Research. The Unit, which holds a large collection of unpublished documents at the disposal of industry, will at present remain at Lacon House, Theobalds Road, London, W.C.1.

STORDY ENGINEERING, LTD., has removed to Cumbria House, Goldthorn Hill, Wolverhampton (Tel.: Wolverhampton 37341–2).

DIARY

4th–15th June—INSTITUTIONS OF CIVIL, MECHANICAL, AND ELECTRICAL ENGINEERS—Joint Engineering Conference—London Offices of the three Institutions.

12th–15th June—INSTITUTE OF BRITISH FOUNDRYMEN—48th Annual Conference—Newcastle-upon-Tyne.

19th June—IRON AND STEEL ENGINEERS GROUP—Fifteenth Meeting—4 Grosvenor Gardens, London, S.W.1, 10.30 A.M.

27th June–3rd July—INTERNATIONAL CONGRESS OF CRYSTALLOGRAPHY—Stockholm, Sweden.

TRANSLATION SERVICE

(The previous announcement was made in the April, 1951, issue of the *Journal*, p. 454.)

TRANSLATION AVAILABLE

No. 420 (German). W. KRÄMER: "The Use of Roller Bearings in the Stands of Mills for Hot-Rolling Thin Plates." (*Stahl und Eisen*, 1950, vol. 70, Oct. 12, pp. 925–929).

TRANSLATION IN COURSE OF PREPARATION

(German). W. PAPSDORF: "Patenting and Drawing Experiments on Austenitic Coarse- and Fine-Grained Steel Wires and the Influence of Small Contents of Carbide-Forming Alloy Elements." (*Archiv für das Eisenhüttenwesen*, 1951, vol. 22, Mar./Apr., pp. 87–98).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether they can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

Iron Ore for Great Britain. H. U. Ross. (Mine and Quarry Engineering, 1950, vol. 16, Mar., pp. 80–84). Sir Charles Goodeve has said that the estimated requirements of imported ores for a production of 17·5 million tons of steel, were 12·5 million tons, an increase of 45% over the 1948 level, and that the bulk of this increase must come from new fields. The Labrador iron range is much closer than the other possible new sources in Africa and South America. The Labrador ore will be loaded at the port of Seven Islands which can be kept open throughout the Canadian winter. With sufficient tonnage coming from one place, the ore, which contains Bessemer, non-Bessemer, and manganiferous grades in enormous quantities, can be graded accurately which would mean a more uniform raw material for British pig iron. The initial objective is 10 million tons of ore a year and it is estimated that it will take three years to complete the rail and harbour facilities.—E. C. S.

The Grängesberg Iron Mines. A. Marsh. (Mine and Quarry Engineering, 1950, vol. 16, Aug., pp. 249–256). Two groups of ores are mined: (1) Apatite ores, of magmatic origin, consisting of coarse magnetite or hematite with a phosphorus content of 0·8–8%. Typical analyses are: Magnetite: 62·12% Fe, 0·19% MnO, 3·26% SiO_2, 0·74% Al_2O_3, 4·58% CaO, 1·06% MgO, 1·28% P; and hematite: 62·15% Fe, 0·09% MnO, 3·91% SiO_2, 0·04% Al_2O_3, 5·00% CaO, 0·11% MgO, 1·42% P. (2) Those of hydrothermal origin, consisting of mixed hematite and magnetite with a phosphorus content of 0·07–0·3%.—E. C. S.

Yugoslav Steel Industry and the Five-Year Plan. (British Iron and Steel Federation Monthly Statistical Bulletin, 1950, vol. 25, May, pp. 12–17). The plan foresees an output of 760,000 tons in 1951 and it is estimated that in 1953 output will reach 850,000 tons. From 1935 to 1939 output increased from 100,000 tons to 235,000 tons. Details of imports from the United Kingdom and data on the ore resources of Yugoslavia are given.—E. C. S.

The Origin of the Pre-Cambrian Banded Iron Ores. T. Sakamoto. (American Journal of Science, 1950, vol. 248, July, pp. 449–474). The bonding in these ores is due to a cyclical deposition of colloids by a periodic change in the *p*H of lake water. The two-component poor ores, with alternating bands of ferric oxides and SiO_2, were produced by an acid–neutral semi-cycle; while the three-component poor ores, with alternating bands of ferric oxides, SiO_2, and iron silicates or carbonates, were produced by an acid–alkaline cycle.

ORES—MINING AND TREATMENT

The Pelletizing of Dogger Ore Concentrate and Siderite. G. Sengfelder. (Stahl und Eisen, 1950, vol. 70, Aug. 31, pp. 765–767). After adjusting the moisture content of fine-grained Dogger ore concentrate and raw siderite, the material is pelleted, dried in an open-ended drum at approximately 70° C., and then fired at 1000–1100° C. in a vertical kiln. A continuous process has been developed for the production of the finished pellets, and it is found that a two-stage firing in the kiln gives a higher output per unit of fuel gas. Experiments have shown that these pellets are reduced more easily than is sintered concentrate.—J. P.

The Smidth Agglomerating Kiln—Plant and Practice at East Moor Works, Cardiff. W. E. Simons. (Journal of The Iron and Steel Institute, 1951, vol. 167, Jan., pp. 1–8). The rotary kiln provides an alternative method to sintering for the treatment of fine ores and flue dust. The construction of a particular kiln and the layout of the plant are described. The operating procedure is outlined and details, including analyses, are given of the ingoing materials and of the finished agglomerate; some of the difficulties and hazards of the process are mentioned. Data are given relating to the use of the agglomerate in the blast-furnace, and the advantages and disadvantages of the rotary kiln are discussed.

FUEL—PREPARATION, PROPERTIES, AND USES

Making the Most of a Waste Fuel. S. Blum. (Blast Furnace and Steel Plant, 1950, vol. 38, Sept., pp. 1066–1071). The article describes the design and operation of the new boilers of the Alan Wood Steel Co. which burn blast-furnace gas, coke-oven gas, tar or oil, separately or in combination. The entire project, including a mile-long pipeline across a river, was designed by the H. M. Wilson Company, Philadelphia, Pa.—J. P. S.

Control of Heaters. M. de Livois. (Chaleur et Industrie, 1950, vol. 31, Nov., pp. 289–298). The gas/air ratio and other factors that must be controlled, their measurement, effects, and methods of control are dealt with generally, and are set out in tabular form. It is important that measuring apparatus should be suitably placed for the operators to see, and various precautions should be taken to safeguard both plant and personnel.—T. E. D.

Trials of an Experimental Austeel-Escher Metallic Recuperator. J. B. Davis, W. Ernest, and H. Kay. (Journal of The Iron and Steel Institute, 1951, vol. 167, Jan., pp. 66–70). A series of trials was carried out on a small Austeel-Escher

metallic recuperator to observe its operating characteristics under widely varying conditions. The paper describes the experimental procedure adopted, and refers to some of the more important data obtained.

The Importance of Automatic Sampling : Potentialities and Applications. J. Visman. (Fuel, 1950, vol. 29, May, pp. 101–105). This paper deals with the sampling of mineral raw materials used for industrial purposes and more generally with the sampling methods for fine and coarse grained mixtures of particles in which the content of one particular constituent has to be determined with a certain accuracy. By regulating the weight of the sample and the number of increments the sampling accuracy of any product (*e.g.*, coal, ore) may be calculated in advance. The need for a large number of increments collected by means of automatic samplers, the admissible minimum weight of increment, the sampling apparatus, the accuracy attained in the application of automatic samplers, and the calculation of this accuracy in advance are discussed. A description is given of an automatic machine for collecting samples of coal travelling on a conveyor belt at the Staatsmijnen colliery. A method for checking the calculated accuracy is described.—J. P. S.

An Investigation into the Relations between Gray-King Assay, Crucible Swelling Number, and Percentages of Hydrogen and Carbon in South Yorkshire Coals. G. H. Jowett, P. H. Price, and R. J. Sarjant. (Journal of the Institute of Fuel, 1950, vol. 23, Nov., pp. 304–307, 322). From the analyses of 90 samples of South Yorkshire coals the following variables were selected and statistically investigated : (1) Gray-King assay coke type ; (2) crucible swelling number ; (3) ultimate analysis (dry ash-free basis)—percentages of carbon and hydrogen. Correlation charts for the three variables are given.—J. P. S.

Concerning the B.S. Swelling Number of Coal. D. J. W. Kreulen. (Fuel, 1950, vol. 29, May, pp. 112–117). The British Standard 1016 (1942) swelling test of coal has been investigated. It is held that the profiles which accompany the standard prescription refer partly to conditions which are unrealizable with the aid of the normal crucibles used in common practice. It has been found that the swelling number fails completely as an index for the evaluation of the coking properties or as a classification index. During the oxidation the swelling number of certain ordinary types of coal passes through a maximum. The existence of this maximum is illusory : it is in fact due to a lag in swelling of the freshly prepared coal sample under the conditions of the test. This lag results from a collapse of the coke button consequent on too low a viscosity of the plastic mass during its formation. Some evidence has been found that the stability of a coal on storage might be derived from the progress in swelling number during oxidation at a higher temperature (100–125° C.). The procedure, however, is rather cumbersome and similar information might be obtained along other and more simple lines.—J. P. S.

The Distribution of Coking Properties in British and Commonwealth Coals. N. Berkowitz. (Fuel, 1950, vol. 29, June, pp. 138–143). A survey was made of some 260 British and Commonwealth coals which showed that coking properties depend neither upon the rank of coals nor upon the proportion of extractable matter that they contain. Instead it is found that coking coals can be defined in terms of their air-dried moisture contents (less than 3·5%) and that the swelling and agglutinating indices of coals of equal moisture content are proportional to their volatile matter contents. These observations are regarded as confirming the thesis that the coking mechanism is primarily determined by the colloidal structure of coals and that their chemical constitution is of minor importance.—J. P. S.

Formation of Coke from Weakly Caking Coal by Rapid Carbonization. W. J. Kramers, M. Pirani, and W. D. Smith. (Fuel, 1950, vol. 29, Aug., pp. 184–187). The authors point out that the swelling and agglutinating power of coal is considerably enhanced by rapid carbonization in thin layers or beds. In this way cokes comparable in strength to a gas or low-temperature coke can be obtained from very weakly caking coals of either high or low volatile matter content. Experiments are described with two particular coals placed in metal containers from 2 to 6 in. wide inserted into electrically heated muffles at 1100° C. The rate of heating in the coal charge and the strength of coke obtained diminished with decrease in furnace temperature and with increase in the thickness of the layer through which the heat had to be transferred. The coal particles may be about 0·125 in. in size, and it is convenient to use coal powders ground to less than 0·125 in. Oxidizing gases must be excluded during the carbonization. Other factors being equal, the use of a high volatile coal appears to be advantageous.—J. P. S.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Blast-Furnace Tuyere Designed to Deliver Air as Required. J. H. Sprow. (Blast Furnace and Steel Plant, 1950, vol. 38, Aug., pp. 928–929). The combination tuyere is, in effect, a tuyere having two different diameters at the nose with a tuyere area approximately that of a round tuyere with a diameter the average of the two. The smaller-diameter segments concentrate a portion of the blast, forcing it to penetrate farther toward the centre than it would normally go through a larger tuyere. The larger-diameter segments spread a portion of the blast further than the smaller tuyere does.—J. P. S.

New American Blast Furnace Designed for Carbon Lining. H. A. Brassert. (Iron Age, 1950, vol. 166, Sept. 21, pp. 92–94). A design for a blast-furnace using a carbon lining inside an all-welded gas-tight structure to exclude moisture is described. All cooling is to be carried out by spray on the outside of the shell except for tuyere and cinder notch coolers. The saving in copper is expected to offset much of the cost of the carbon. A suggested method of eliminating moisture at the taphole is by using thermosetting plastics admixed with the clay instead of water.—A. M. F.

Iron Smelting Problems. E. C. Smith. (Metal Progress, 1950, vol. 58, Nov., pp. 721–724). The life of blast-furnace linings is still unpredictable, though the European use of carbon blocks is encouraging. High-pressure operation is now satisfactory with respect to dust losses, and it remains to find the effect of pressures above 12 lb./sq. in. The reducibility of various iron ores has not been sufficiently studied. The author ends with a few personal opinions on the needs of the American smelting industry—adequate transport, and low taxes.—E. T. L.

Operation and Shape of Blast Furnaces for Smelting Raw Fine Ores. E. Nowak. (Stahl und Eisen, 1950, vol. 70, Sept. 14, pp. 829–836). The difficulties in smelting fine ores have led to an investigation into the conditions in the furnace shaft. The top gas evolved during the blowing out of a furnace was analysed, while the composition of the burden was maintained normal as long as possible, and the top of the burden sprayed with water from below the throat. It was shown that in the upper 2·0–2·5 m. of the normal burden there is a very large amount of indirect reduction. This reduction in such a small region at the top of the shaft is of supreme importance for the whole smelting process. This must be so conducted that the conditions are favourable for indirect reduction : the iron must be present as Fe_2O_3, whether in raw ore, roasted ore or sinter. The investigation showed that in the smelting of fines, somewhat reduced blast and blast temperature favour indirect reduction and lead to uniform driving. In spite of its fineness, a heavy charge of ore is necessary to lower the temperature of the shaft. The fine-grained ore is reduced early to iron or iron carbide which catalyses carbon deposition ; this is important for reduced coke consumption. Uniform driving is equally favourable in this direction, so that the combustibility of the coke and the correct furnace profile also possess certain importance. The furnace working at maximum efficiency is, however, in labile equilibrium. Any slight disturbance, *e.g.*, excessive lowering of the stockline, may lead to severe difficulties. The best, and not the maximum, output should be aimed at. The best efficiency in the smelting of fine ores is attained with a somewhat reduced output. In order to obtain the same production as with a sized burden, the furnace must be larger. This led to a decision to rebuild a furnace with thinner walls, so increasing the capacity for the same external dimensions. This has shown that it is possible to smelt fine ores successfully and economically in the blast-furnace.—J. P.

Methods of Modifying Top-Gas Composition and Their Influence on the Utilization of Heat in the Blast-Furnace. P. Thierry and J. Szczeniowski. (Revue de Métallurgie, 1950, vol. 47, Oct., pp. 739–759). The higher the working index $i = CO_2/CO$ the better the coke rate, since less potential

heat is lost in the gas. The reactions affecting i are: Percentage indirect reduction; amount of carbon deposition; reactions due to undesirable coke reactivity in the stack; decomposition of part of the water of hydration by CO (improving i but giving no thermal benefit); and decomposition of carbonates. The value of i may be increased by: Improving the reducibility of the ore; increasing the surface of contact of the ore by crushing large lumps and working with the smallest possible ore/coke ratio; increasing the time of contact by better gas distribution; increased top pressure; a lower rate of working with periodic return to normal rates to cut down scaffolding; and increasing the height of the stack (perhaps the best method). The calorific effect of improving the working index is calculated for various conditions, and the effect of the inertia of the blast-furnace is considered. Experimental results, including gas composition after checking the furnace and the effect of variations in i on the iron analysis, are given. Owing to the numerous parasitic reactions which increase i without any calorific gain, comparisons of working rate are only useful for charges of similar composition. If the working rate is not constant false results are obtained due to inertia. Variations in rate should be more gradual the larger the furnace. A permanent record of top-gas composition enables adjustments to be made in time to check bad tendencies.—A. G.

Distribution of Materials in the Blast-Furnace. Part III—Further Factors Influencing the Distribution of Solids in the Blast-Furnace. R. Wild. (Journal of The Iron and Steel Institute, 1950, vol. 166, Dec., pp. 339–348). Previous studies (*see* Journ. I. and S.I., 1949, vol. 163, Sept., pp. 61–70) on the distribution of materials in the blast-furnace are extended to further consideration of the effects of modifications in (1) design and operation of the head-gear and (2) the nature of the materials charged. Conclusions drawn from the investigation are enumerated.

Technical Aspects of Northern and Southern Blast-Furnace Practice. C. G. Hogberg. (Iron and Steel Engineer, 1950, vol. 27, Oct., pp. 37–47). The author studies slag volume and coke consumption in blast-furnaces by comparing blast-furnaces employing widely different slag volumes. These differences are readily provided by the practices in the northern and southern regions of the U.S.A. Detailed and tabulated comparisons are given of furnace design and the different types of ore. Comparative tables of chemical analysis, density, and screen analysis of burdens are also given. The effects of scrap and flux are studied as well as the effects of slag on fuel consumption. Detailed information is also provided on the descent of furnace stock, heat developed in the hearth, high blast temperature, and erosion of furnace linings.—M. D. J. B.

The Influence of Carbon Content on the Desulphurization of Molten Iron in a Lime–Fluorspar Crucible in an Induction Furnace. W. A. Fischer and T. Cohnen. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Nov.–Dec., pp. 355–365). Attempts to desulphurize liquid iron in a lime crucible in an induction furnace were unsuccessful, sulphur contents being reduced by only about 30%. This was attributed to the restricting action of lime/iron-oxide compounds on the surface of the crucible. Exploratory tests showed that CaF_2 had in itself no desulphurizing action but that in a lime–fluorspar crucible (15–20% CaF_2) good desulphurization was possible. Liquid iron at 1620° C. was brought to equilibrium with respect to carbon and sulphur in such crucibles under an atmosphere of CO at approximately 1 atm. pressure. The relationship $[C\%][S\%] = 0{\cdot}011$ was found to hold to a high degree of accuracy over the range of carbon contents 0·1–3·0%. When combined with the Vacher-Hamilton equation, $[C][O] = 0{\cdot}0025$, this implies that $[S] \simeq 4[O]$. If the oxygen contents of the melts were reduced by the addition of manganese, silicon, or aluminium, a further large reduction in sulphur content resulted, and the extent of the desulphurization was proportional to the deoxidizing power of the added metal. Over the range 1400–1700° C., the carbon–sulphur equilibrium was independent of, but the velocity of the desulphurization reaction rose markedly with, temperature, probably as a result of increased diffusion rates of sulphur in metal and slag. Reaction rates were increased by high carbon contents. When the melts were tapped in the presence of air and slag, there was a rapid resulphurization, which could, however, be avoided by the use of an inert protecting atmosphere.—J. P.

Blast-Furnace Foundry Pig Iron and Hematite. J. Šárek. (Hutnické Listy, 1950, vol. 5, Nov., pp. 443–445). [In Czech]. The influence of the blast-furnace operation and slag composition on the quality of pig iron and hematite iron produced is discussed, and it is shown that insufficient attention is given at the furnaces and in foundries to grain size.—E. G.

PRODUCTION OF STEEL

The Design of Iron and Steelworks. W. F. Cartwright. (Proceedings of the South Wales Institute of Engineers, 1950, vol. 65, Apr., pp. 104–123). A description is given of methods evolved by the author as a result of his experience in planning and design of two large steelworks. Before any drawing can be done, decisions (which are listed in detail) have to be taken regarding the tonnage of each product and the system of manufacture from raw material to finished article, and the extent to which new processes and methods shall be introduced. Having settled the broad outline of the scheme, the designers must prepare drawings and a report which describes the plant and services, estimates roughly the capital and operating costs and the manpower needed, and gives fuel, water, electrical and steam balances, and statistics of output, etc. Design of services is hampered by the lack of accurate data on consumption of water, steam, electricity, and the volume and temperature of waste products. The fuel balance is most important. The use of coke-oven and blast-furnace gases, breeze and tar, the alternative fuels which may be purchased, and the extent to which furnaces shall be fitted with waste-heat boilers, must be decided. Flexibility in the use of by-product fuels is necessary to avoid dislocation when one unit breaks down or alters its demand and this is most easily achieved by varying the amount of power generated, using blast-furnace gas, as opposed to power purchased. A suitable organization of departments is described. The general plant and layout section decides positions of buildings and layout of their services. Working models are useful in deciding on sidings layout and number of handling units (cranes, chargers, etc.) required. The civil engineering section examines the site and the soil. Buildings and foundations should be designed together, as foundation drawings are usually a bottleneck in design. The steam engineer must decide on the steam pressures, balancing high efficiency against low first costs. The problem in deciding on type of steelplant is whether to use basic-Bessemer, tilting open-hearth, or fixed open-hearth plant or a combination of these. In designing cranes, more attention should be paid to safety, as they are responsible for a high proportion of fatal accidents. Melting-shop slag is often inefficiently handled, and details of a method adopted by the Steel Company of Wales, are given. Materials should be handled by belt where possible. The choice between diesel and steam locomotives is difficult because the former have not been in service anywhere for sufficient time to produce reliable cost figures. Amenities, heating, cooling, ventilation, and the place of architecture are also dealt with.—H. R. M.

What's Ahead in Steelmaking? J. D. Knox. (Steel, 1950, vol. 127, Sept. 18, pp. 111–113, 136). A brief review of the latest developments is given including the processing of Taconite, high top-pressure operation in blast-furnaces, continuous casting, the turbo-hearth steelmaking process, the use of oxygen, charging systems, and increased mill-operating speeds.—A. M. P.

Recent Progress in Modernisation at Consett Iron Company, Limited. (Iron and Coal Trades Review, 1950, vol. 161, Dec. 22, pp. 983–986). **Plant Reorganisation at Works of Consett Iron Company, Limited.** (Metallurgia, 1951, vol. 43, Jan., pp. 20–24). **Reconstruction and Development Projects of the Consett Iron Company, Limited.** (British Steelmaker, 1951, vol. 17, Jan., pp. 21–25). A brief description is given of the extensive reconstruction scheme of the Consett Iron Co., Ltd., which includes new coke ovens and blast-furnaces, steel furnaces rebuilt to twice their previous capacity, centralized steam and power generating plant, and new rolling mills. The works will provide two important additions to national steel production, in medium slabs, 10–12 in. wide × 4–6 in. thick, for medium-width strip, and rolled semi-finished material for re-rolling and drop forging. At present both types of product are imported to a considerable extent.—G. F.

Steel Production at the Lanarkshire Steel Company, Limited: Modern Plant and Equipment at Flemington. (Iron and Coal

Trades Review, 1950, vol. 161, Nov. 10, pp. 637–640). The works of the Lanarkshire Steel Co., Ltd. consists chiefly of the open-hearth furnace plant; blooming and slabbing mills; heavy, medium, and light section mills; fabricating department producing all classes of structural steelwork; a special plant producing colliery arches and props; and maintenance service shops. The modernization scheme begun in 1936 is outlined, and the production departments are described in some detail. A wide range of products for the shipbuilding and general engineering industries is made, the ingot output in 1949 being 307,000 tons.—G. F.

A Modern Steel Works. (Edgar Allen News, 1950, vol. 29, May, pp. 565–567; June, pp. 597–599; July, pp. 625–628). The works of Guest Keen Baldwins Iron and Steel Co., Ltd., East Moors, Cardiff, are described. The melting plant consists of three 230-ton tilting basic open-hearth furnaces, one 600-ton active mixer, two 90–100-ton fixed basic open-hearth furnaces and two 250-ton tilting furnaces. It is equipped with three Wellman and two Broadbent revolving open-hearth chargers, three 60-ton overhead cranes, and two Blaw-Knox machines for fettling the back-walls of the furnaces. The casting ladles are of 90 to 100 tons capacity. Ingot moulds of both direct and uphill teeming types are carried on roller-bearing bogies. Two of the seven teeming stands are equipped with exhaust fans and filtering systems for use in the manufacture of lead bearing steels. The soaking-pit plant on the Isley system consists of 18 rectangular soaking pits. The rolling mills consist of a 40-in. Sack blooming mill, a Morgan continuous sheet bar and billet mill, and a 21-in. Lamberton 3-stand 3-high light section mill.—E. C. S.

Iscor's New Blast-Furnaces and Steel Works at Vanderbijl Park: Post-War Project Accelerated by World Steel Shortage. (Iron and Coal Trades Review, 1950, vol. 161, Oct. 6, pp. 551–555). A brief outline is given of the main features of the newly extended iron and steel works at Vanderbijl Park, South Africa, which will give an output of about 240,000 short tons per annum of flat rolled sheet products. Brief descriptions are given of the new coke ovens and by-products plant, the blast-furnace and open-hearth furnace plants and their auxiliary equipment, and the rolling mills, which include a slabbing-blooming mill, an existing plate mill, a hot strip mill, and cold mills.—G. F.

Lone Star Steel Rapidly Increasing Service in the Southwest. C. Longenecker. (Blast Furnace and Steel Plant, 1950, vol. 38, Sept., pp. 1042–1049). The history of the company since 1947 is outlined. Raw materials are readily available. The coke-oven plant, blast-furnace, cast-iron pressure pipe department, and steel plant are either producing or are under construction. The present and intended plants are discussed.
J. P. S.

Chile Now a Producer of Steel with Fully Integrated Plant. (Blast Furnace and Steel Plant, 1950, vol. 38, Nov., pp. 1285–1322, 1336). This article deals with the steel plant of the Compania de Acero del Pacifico, recently completed in collaboration with Koppers Company, Inc. The cost of the plant exceeded 75 million dollars. The supply and handling of raw materials are discussed. A description is given of the coke ovens, producer plant, and tar and ammonia removal plant. Details are given of the blast-furnace, which has a capacity of 600 tons/day, and its auxiliary equipment. The construction and operation of the Bessemer converter and the two open-hearth furnaces are discussed. Details are given of the blooming, billet, and sheet-bar and bar mills. The plate, sheet, and tinplate mills are also described. Annealing furnaces, tinning facilities, boiler house, and stand-by turbo-generator, pump house, gas distribution system, electric power distribution system, and maintenance and service facilities are also dealt with.—J. P. S.

De-Dusting the Bessemer Converter. W. Trinks. (Blast Furnace and Steel Plant, 1950, vol. 38, Sept., pp. 1040–1041). The author surveys the difficulties which at present make the elimination of brown smoke from the Bessemer converter impracticable.—J. P. S.

Stud Welding Speeds Steel Production. R. C. Singleton. (Iron and Steel Engineer, 1950, vol. 27, Oct., pp. 100–104). Modern construction of open-hearth furnace doors is considered and recent developments are described in door design which combine the use of plastic chrome ores and end-welded studs. The end-welded studs used in the doors serve two purposes. One is to provide proper support for the rammed chrome ore. The other function is to provide a heat transmission path from the hot surface of the door to the cooling tank behind in order to keep the insulating material as cool as possible. The stud size and spacing, the proper ramming procedure, and the correct curing of the ram material are examined. Comparative figures are given showing the advantages of studded and rammed doors over brick doors.
M. D. J. B.

Novel Openhearth Has No Front Wall. S. Ichida and D. I. Brown. (Iron Age, 1950, vol. 166, Sept. 21, pp. 85–87). The Amagasaki Steel Manufacturing Co. in Japan have had in use since January 1949 an 80-ton furnace with a suspended roof and all-door front with the two specific objectives of longer roof life and faster charging to obtain the maximum benefit from the use of oxygen. An important change in design is the individual suspension of the silica roof bricks. A new charging machine is being designed to charge scrap up to 21 ft. in length. There is an increase in furnace productivity of 20%.—A. M. F.

Specifications for Open Hearth Charge Oxides. (American Iron and Steel Institute, Aug., 1950, Contributions to the Metallurgy of Steel No. 36). This report proposes a specification for the properties of basic open-hearth charge ores and sinters, and discusses the influence of these properties on furnace operation. The specifications are based on the replies from 18 companies, covering 25 furnace sizes and 53 different hot metal practices, to a questionnaire submitted to member firms of the Technical Committee on Open Hearth Steelmaking of the American Iron and Steel Institute. The replies are concerned with six types of charge oxide, namely, soft ore, lump ore, magnetite ore, sinter, nodules, and block iron. The properties covered by the specification are: Physical size; apparent and bulk densities; combined and natural moisture contents; iron, sulphur, phosphorus, and carbon contents; acid and basic oxides contents; and the content of residual elements. An appendix deals with the determination of apparent specific gravity of charge oxides.—G. F.

Evaluation of Open-Hearth Furnace Data during a Complete Campaign. I—65 and 85-ton Furnaces. W. Baumgardt and K. G. Speith. (Stahl und Eisen, 1950, vol. 70, Sept. 28, pp. 877–881). Data from two Maerz furnaces, of similar construction but operated in two independent works, show that in spite of somewhat different working conditions, all characteristics, such as fuel consumption, output, slab bulk, etc., are very similar, particularly if regard is paid to the different capacities.—J. P.

Evaluation of Open-Hearth Furnace Data during a Complete Campaign. II—100 and 150-ton Furnaces. G. Henke and W. Schleicher. (Stahl und Eisen, 1950, vol. 70, Sept. 28, pp. 881–883). All important data on melting conditions, metallurgical processes, furnace outputs, fuel consumption, etc., were collected during complete campaigns in a 100-ton cold-gas-fired Hoesch furnace and a mixed-gas-fired Friedrich 150-ton furnace. Hourly outputs and heat consumption per ton of steel were evaluated under different conditions, such as hot as against cold pig or variable amounts of pre-blown duplex metal, and compared with themselves and with those of two smaller Maerz furnaces. The average figures were in good agreement and the results should therefore be of value to other steelworks.—J. P.

Applications of the Statistical Analysis of Factors Affecting the Output of an Open-Hearth Furnace. P. Arnold and M. W. Thring. (Journal of The Iron and Steel Institute, 1951, vol. 167, Jan., pp. 44–45). The statistical analysis described in a paper by Robertson and Thring on factors influencing the output of an open-hearth furnace has been applied to further data and has given a relation between (*a*) the carbon content of the fully melted steel, (*b*) the weight of oxygen required to oxidize carbon, silicon, phosphorus, and manganese in the original charge, and (*c*) the rate of oxidation. The effect on the output of increasing the flame radiation is twice as great if the oxygen equivalent of the initial charge, instead of being kept constant, is reduced by such an amount that the melt-out or 'junction' carbon is the same as it was with the original flame. It is also shown that if a method of feeding the carbon back to the charge in soft melts were available, a 5% gain in output would result from reducing the oxygen equivalent of the initial charge to give the average carbon at melt-out equal to the previous lowest permissible value.

A Theory of Basicity and Oxidation Applicable to Steelmaking. W. L. Kerlie. (Journal of The Iron and Steel Institute, 1951, vol. 167, Jan., pp. 9–26). A re-examination of some of the literature on the subject has been carried out, particular attention being given to the influence of slag basicity on the distribution of FeO between slag and metal. As a consequence a theory of oxidation and basicity has been developed by which the equilibrium oxygen content of the liquid iron can be calculated with reasonable accuracy, given the total iron content of the slag, the temperature, and the basicity. On the molecular theory of slag/metal equilibria it appears necessary to assume the presence of relatively inactive $(FeO)_4$ molecules, the stability of which increases with increasing basicity. There is a range of slag basicity within which the slag behaves more or less as an ideal solution, the activity of the FeO being essentially directly proportional to the mol fraction. At lower values of basicity there is a positive deviation and at higher basicities a negative deviation from Raoult's law. These deviations indicate that with neutral slags there is a high degree of dissociation of the $(FeO)_4$ molecules. A similar effect with acid slags is also apparent. Using calculated values of oxygen content the equilibrium constants for the phosphorus and manganese reactions have been evaluated and compared with the constants based on analytical oxygen contents. The distribution of sulphur between metal and slag indicates that the FeO in the slag has two different actions, depending on its concentration and the basicity of the slag, and suggests the presence of dissociable $(FeO)_4$ molecules. A special series of experiments on a production scale in a basic Bessemer converter has shown that the oxygen content of the steel is an important factor influencing the final nitrogen content. The importance of other factors is revealed by a simple method of examining mass data. The examination of experimental data on open-hearth heats reveals the possibility of an improvement in the refining technique.

Thermal Analysis of Open-Hearth Furnace Operation. A. Benda. (Hutnické Listy, 1950, vol. 5, Nov., pp. 454–457). [In Czech]. The efficiency of heat utilization in the iron and steel industry is considerably lower than in the electricity supply industry. Most investigations on fuel consumption in the metallurgical industry have been purely statistical. The author carried out a mathematical analysis of the factors which influence the fuel efficiency of open-hearth furnaces and developed formulæ for determining fuel consumption, and for the relation between specific fuel consumption and stack draught. The equations are used to indicate the measures to be taken to increase the fuel efficiency after a simple calculation of the heat and draught characteristics.—E. G.

Improvements in Electric Furnace Design. F. V. Lewis. (Foundry Trade Journal, 1950, vol. 89, Dec. 14, pp. 505–506). A comparison is made between the contactor type of electrode control gear and a rotary controller in the operation of a model T.S. Birlec Lectromelt 300-kVA. ½-ton furnace. Advantages claimed are that danger of 'hunting' and the duration of overload are reduced, and savings of up to 10% kWH./ton, up to 15% of the time per heat, lower refractory cost, and a 25% reduction in electrode consumption. A type of electrode gland operated by the magnetic field of the electrode is described.—J. W. P.

Trends in Electric Arc Furnace Practice. D. L. Clark and J. A. Clark. (Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 103–110). A comprehensive discussion is given on the modern trends in electric arc furnace practice and design. A brief historical review is given from Heroult's first direct arc furnace of 1886 to the latest types. Door charging and top charging are discussed and, on a cost-saving basis, preference is given to top charging for all sizes of furnace. The height of side plates and the advantages of welding combined with bolting are considered. Electrodes, electrode holders and regulators, circuit breakers, voltages and tap changers, and transformer capacity are the subjects of careful analysis. Consideration is also given to refractories, exhaust systems, and dust control. Melting capacity, production, operations, and costs are also dealt with. The authors conclude that the arc furnace has gained its prominence by the manufacture of quality steels, its versatility in eliminating undesirable elements or conserving costly or strategic alloys, and because of its flexibility of operation.—M. D. J. B.

The Electric Furnace in Production for Fifty Years. J. A. Clark. (Blast Furnace and Steel Plant, 1950, vol. 38, Oct., pp. 1163–1165). The rise to importance of the electric steel furnace is reviewed. General details are given of construction, auxiliary equipment, and practice.—J. P. S.

Oxygen Technique Salvages Stainless Steel Scrap. (Steel, 1950, vol. 127, Aug. 28, pp. 87–88). **The Use of Oxygen in Steelmaking.** (Engineer, 1950, vol. 189, June 16, pp. 717–718). **Oxygen Lancing in Electric Arc Furnaces: Complete Stainless Steel Scrap Charge in New Technique.** (British Steelmaker, 1950, vol. 16, July, pp. 350–352). The use of the oxygen in the production of 18/8 stainless steel in arc furnaces at the works of Edgar Allen and Co., Ltd., and Brymbo Steel Works, Ltd., is described (*see* Journ. I. and S.I., 1951, vol. 167, Feb., p. 214).

Chromium–Silicon Alloys in the Manufacture of Stainless Steels: a New Technique of Slag Reduction Developed in Sheffield. D. J. O. Brandt and W. H. Everard. (Iron and Coal Trades Review, 1950, vol. 161, Sept. 29, pp. 525–528; Metal Treatment and Drop Forging, 1950, vol. 17, Autumn Issue, pp. 167–170). A description is given of trials at Messrs. Edgar Allen and Co., Ltd., of a new technique of reducing chromium oxides from the slag during the oxygen-lancing method of manufacturing 18/8 stainless steel from 100% stainless scrap charges in the electric arc furnace. A consideration of the economics of the technique indicates that a saving of about £2 per ton of stainless steel made will be effected.—G. F.

Babcock and Wilcox Tube Company Develops Continuous Casting. I. Harter, jun. (Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 57–72). This article describes the development and expansion of a number of Babcock and Wilcox works. Historical and statistical information on the plant is given as well as details of the tube mills and the hot-finishing department. Development work on the continuous casting of steel at the Beaver Falls plant is described. The equipment comprises a ladle, pinch (or withdrawal) rolls, a transfer car, instruments, and an inductively heated holding ladle designed and built by the Company and powered with a high-frequency generator of only 250 kW. capacity. Molten steel, melted in a 12-ft. electric arc furnace or in a 5000-lb. induction furnace in the steel plant, is hoisted to the casting floor and is there bottom-teemed into the holding ladle. The tilting of the ladle is governed by the manual operation of control rheostats and metal flows into a tundish (or slag-eliminating container) and thence into the mould. Over 200 heats have been cast in the tower, some of these as 4-in. rounds, some 6-in. rounds, a few in rather pointed ovals, and now a $9 \times 4\frac{1}{2}$ in. oval mould has been developed. Approximately 130 tons of continuously cast steel have been supplied against trial orders. Present equipment does not permit casts of more than about 15 min. duration. The problems encountered in the process are briefly mentioned and the prospects of future development discussed.—M. D. J. B.

The Practice of Bottom Pouring Steel. C. R. Funk. (Blast Furnace and Steel Plant, 1950, vol. 38, May, pp. 515–520; Aug., pp. 899–907). The bottom-pouring of steel is described. The main advantages, which are discussed, are the use of long moulds, longer mould life, cleaner ingot surface, larger ingot yields, and cleaner steel. The disadvantages of bottom-pouring as compared with top-pouring are outlined. Details of plate and centre runner design are given. Brick design and brick quality are discussed. The assembly for bottom-pouring is outlined. The author points out that to make good quality bottom-poured steel all component parts of the assembly must be properly designed, details of assembly must be strictly controlled and attention must be given to proper deoxidation and control of metal temperature.—J. P. S.

Electric Hot Tops for Ingots. D. D. Howat. (Iron and Coal Trades Review, 1950, vol. 161, Nov. 10, pp. 643–644). The author briefly discusses the use of the electric arc, in this country and in America, to maintain a reservoir of molten metal in the hot tops of castings and ingots. Its use is said to reduce by about one half the amount of metal required in the hot top, amounting to as much as 40% of the total in certain castings, and to give a higher and more consistent ingot yield.—G. F.

FOUNDRY PRACTICE

The Foundry, the Engineer and the Future. J. G. Pearce. (Foundry Trade Journal, 1950, vol. 89, Oct. 26, pp. 343–346).

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The design of castings may perhaps be improved by concentrating attention on the following three points: (1) The connection between composition and strength of the material in a test bar, and the connection between strengths of test bars of various sizes. (2) Relations between engineering tests, (3) The connection between strength of the test bar and strength in the corresponding castings. Relationships have been shown by Angus, to exist between the carbon equivalent, tensile strength, and section thickness. Control of the matrix and the form of the carbon has produced irons having high strength, high proof stress, and fatigue resistance. A relationship exists also between the tensile strength and the Brinell hardness number; it is therefore possible to estimate the strength in a casting from a knowledge of its hardness and that of the respective test piece.—J. E. W.

Ten Years of Advance in Ferrous Foundries. J. T. Mackenzie. (Metal Progress, 1950, vol. 58, Oct., pp. 499–502). Improvements of the last decade have greatly increased the efficiency, quality, and production of iron and steel founding, and also have improved the working conditions. Amongst the technical advances mentioned are basic-lined cupolas, synthetic resin binders, centrifugal casting of thin-walled pipe, and the use of inoculants for both grey and nodular iron. Other improvements in America are the Foundry Educational Foundation, better methods of inspecting cast iron, and close-tolerance casting.—E. T. L.

Measurement and Control of Gaseous Flows in the Foundry. H. Laplanche. (Fonderie, 1949, Nov., pp. 1819–1835; Dec., pp. 1851–1868). The ideal conditions of combustion in the cupola and the relationships between the rate of combustion, the air blast, and the carburizing or oxidizing of the metal, are explained. The author then reviews general methods of measuring gas flow in mains, paying particular attention to the applications of these methods in the foundry. The importance of the trend towards automatic control of the blast is emphasized and the principles of some present-day control equipment, including differential manometers, Pitot-Ritter apparatus, diaphragms, and industrial flow meters are explained. The measurement of the quantity of blast in the cupola is examined in the light of the relationships between the following factors: (*a*) The quantity of air blown in, its pressure, the internal diameter of the cupola and the height of the charge (Yungbluth's formula); and (*b*) coke consumption, air flow, and hourly output of iron. Yungbluth found that, for a given amount of coke, the melting capacity is a linear function of the quantity of blast.—R. S.

Wear of Cupola Lining. P. Nicolas. (Fonderie, 1949, Nov., pp. 1837–1838). The factors influencing the wear of cupola linings are: Thickness of lining; size of tuyeres; distribution of blast amongst tuyeres; quantity of blast; amount of slag; and type of refractory used. With good dimensions (especially a fairly thin lining), and with good working conditions, excellent results will be obtained either with compressed silico-aluminous bricks (18 to 20% alumina) or by the use of a siliceous ramming mass with 6 to 8% alumina with a certain proportion of coarser silicon elements. In the latter case, care must be taken in ramming and drying.—R. S.

Methods of Producing Nodular Cast Iron. R. Collette and A. De Sy. (Société Française de Métallurgie: Foundry Trade Journal, 1950, vol. 89, Dec. 14, pp. 495–498). The production of nodular cast iron by the addition of the elements cerium, magnesium, lithium, calcium, strontium, and barium or alloys containing these elements is described. Partially successful results were obtained using sodium, potassium, tellurium, and boron. The authors conclude that treatment with magnesium is the most economical and gives the best actual results. A table showing the yield of magnesium obtained using MgNi, MgNiC, MgCu, MgNiSi, and MgNiSiFe alloys is given.—J. W. P.

Nodular Iron; Theory and Practice. (Metal Progress, 1950, vol. 58, Nov., pp. 729–731). Report on a conference held recently at Massachusetts, including a discussion of the structure of graphite, spherulite, and methods of producing them with cerium, calcium, magnesium, zinc, cadmium, bismuth, or tellurium. In pure iron–carbon alloys the spherulite can be formed merely by rapid cooling. There was some discussion as to whether the spherulite nucleates on graphite or magnesium, and a difference of opinion as to the importance of ductile iron. On the one hand it was pointed out that it has the strength of steel and the ease of manufacture of cast iron. On the other, it is now emphasized that it is difficult to guarantee the magnesium content to be within the narrow range needed in large-scale production. The influence of inoculation is affected by the sulphur content, and so desulphurization was discussed.—E. T. L.

The Steel Foundry. A. Guédras. (Métallurgie, 1950, vol. 82, July, pp. 551–553). The main features of steel-founding, using cupola and converter, are sketched. Some general remarks on moulding, pattern-making, stress-relieving, and deoxidation are made. Precautions for making ladle additions are listed and the author's opinion regarding the causes of surface blow-holes is stated.—R. S.

Economic Methods of Producing Cast Steel Fittings. J. Přibyl. (Hutnické Listy, 1950, vol. 5, Nov., pp. 458–464). [In Czech]. Economic mass-production methods for cast steel valves and pipe fittings are described. Drawings and photographs of the proposed casting methods are given. The author gives data comparing the economics of the methods.—E. G.

Standardisation of Moulding Sand Testing and the Water Absorption Power Included. M. Stap. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 200–218). [In English]. Well-known methods of testing the clay content size, moisture content, permeability, strength, and sintering point of foundry sands are surveyed. The determination of the hygroscopicity of the bonding agent cannot be regarded as a direct testing method for moulding sand, but it is a very practical indirect method, especially for synthetic moulding sands. The Enslin apparatus for determining the quantity of water absorbed per unit of weight of dry clay consists of a porous plate for the clay sample connected to a micro-burette by a **U**-pipe. The plate and the burette are on the same level. The apparatus is filled with distilled water. The quantity of water absorbed is read off periodically. The water absorption is defined as the quantity of water absorbed in 24 hr. It is suggested that the Enslin test is acceptable as a criterion for the choice of bonding agent in synthetic foundry sands. The Swagerman method for the determination of the clay content was found to be the most suitable.—R. S.

The Adherence of Sand on Steel Castings. P. R. Beeley and H. T. Protheroe. (Journal of The Iron and Steel Institute, 1951, vol. 167, Feb., pp. 141–157). The first part of the paper details methods employed for the visual comparison of the degree of roughness on steel castings, and for a numerical assessment of penetration. A relationship between metal penetration and sand adherence has been established. The temperature limit at which adherence occurs, in the case of the standard casting adopted, has been determined for casting temperature, metal composition, and sand conditions. The conditions at the sand/metal interface are considered in relation to adherence, and an explanation of the mechanism of adherence is given. The product of the reaction between the metal and sand is the iron silicate $2FeO.SiO_2$. A second section deals with the effect of varying the bond of the sand. The relative merits of various mould paints have been determined; Corefrax, sillimanite, fused alumina, zircon, and plumbago are compared with silica flour. The effect of changing the bond in any paint has also been investigated. An examination of some industrial samples exhibiting severe burning-on is included.

Rationalisation of Sand Preparation. J. F. Goffart. (Institute of British Foundrymen: Foundry Trade Journal, 1950, vol. 89, Oct. 12, pp. 319–326). After examining the nature and occurrence of quartz sands, the mechanism of the bonding action of natural clays and other bonding agents are discussed. Clay bonded sands are the only type which require that all individual grains shall be initially coated with a uniform layer of the bond. In this case therefore the external surface of the grains is important. After summarizing the characteristics of foundry moulding sands, their deterioration after casting is described. The operations necessary to restore the sand are: (*a*) Returning the water of saturation to the clay; (*b*) crushing the hard lumps; (*c*) removal of metallics; (*d*) removal of fines, burnt clays, and cinders, etc.; (*e*) aerating the reclaimed sand; and (*f*) cooling the sand to below 40° C. The cycle of operations can be performed by the following equipment: (*a*) A crusher; (*b*) a screen; (*c*) magnetic separators; (*d*) a dust separator; (*e*) a mill; and (*f*) an aerator and pulverizer. The layout of a sand reclamation plant can be divided into two main operations, (1) preparation and (2) regeneration.—J. E. W.

Reorganisation of a Moulding-Machine Section. R. F. Ottignon. (British Steel Founders' Association : Foundry Trade Journal, 1950, vol. 89, Dec. 7, pp. 467–472). In the moulding-machine section of the foundry of K. and L. Steel Founders and Engineers, Ltd., Letchworth, a complete reorganization (aimed at the reduction of the man hours per ton of castings produced by half) has been nearly completed. The average weight of the castings produced is 20 lb. with a maximum of about 1 cwt. In the original layout the machines were served by heavy-duty travelling cranes which proved too slow in operation. Now the section is independent of cranes, and mechanized shake-out has greatly reduced wear on the moulding boxes.—J. W. P.

The Manufacture of Metal Patterns and Core Boxes without Machinery by the Clay-Plaster Method. J. van Yperen. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 242–252). [In English]. In the clay-plaster method of making metal patterns and core boxes, the pattern is made from modelling clay or plaster. A plaster mould is then cast, in which the plaster core is made. From the core, the core-box halves are made for the final metal pattern and core-box part castings. Practical examples are illustrated and described, step by step. This method is compared with wood pattern-making from the technical and economical points of view.—R. S.

Better Cores at Lower Cost by Electric Baking. V. E. Hillman. (Iron Age, 1950, vol. 166, Sept. 28, pp. 67–69). Two years' production experience at the foundry of the Crompton and Knowles Loom Works has shown that electronic equipment yields better cores much more rapidly and at lower cost than did the oil-fired equipment previously used. The average baking time is 2 min. Overbaking cannot occur, and the use of synthetic resins has been found to be highly economical.—A. M. F.

Evolution and Present Situation of Core Binders. P. Nicolas. (Fonderie, 1950, Oct., pp. 2209–2215). Foundry cores have two essential characteristics : (1) Sufficient green strength for manipulation before stoving ; and (2) enough dry strength to resist the action of metal in casting. Most French founders used linseed oil before the war to prepare their core sands. Owing to the present shortage of linseed oil, two main classes of core binders are now used : (1) Substitutes for linseed oil designed to give strength after baking ; and (2) binders to give both green and dry strength. The factors leading to the shortage of linseed oil in France are explained. A test for green strength is based on rupturing a specimen and weighing the fragments. The strength after baking is determined by applying an increasing transverse load to bend the test piece. The loss in strength after being subjected to a humid atmosphere is measured by bending a number of specimens immediately after baking and cooling in a drier and also after 24 hr. in a saturated atmosphere at 35° C. The variations in rupture load after being subjected to a humid atmosphere are determined as a function of the time of baking. A specification for core binders agreed by the Centre technique des Industries de la Fonderie is given. The label ' AGLOFRAN ' is the official stamp of quality.—R. S.

Prevention of Explosions in Foundry Stoves. P. Rigaut and G. Ulmer. (Fonderie, 1950, Oct., pp. 2221–2223). Accidents can happen when attempts are made to relight a foundry stove, owing to the presence of combustible gases. With coke firing, the stove must not be allowed to work as a gas producer if explosions are to be avoided. There is an optimum height of fuel bed on the grate in relation to the size of coke used. If this height is exceeded, the hearth works as a gas producer and produces CO by combination of the CO_2 produced in the lower zone with the carbon of the coke of the upper zones of the fuel bed. If the optimum height of the coke bed is not reached, the combustion gases contain excessive air and the performance is lowered. Amongst the safety devices described are a direct-draught trap to short-circuit the reverse-draught chimneys of coke-fired stoves. In the case of gas or oil firing, safety valves and hot gas escape tubes can be fitted. Safety devices and precautions to be taken with burners are described.—R. S.

The Manufacture of Ingot Moulds in Cement Sand. J. G. P. Bruschke. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 234–941). [In English]. A special moulding method was developed by the Werkspoor N.V. based on the use of cement sand for moulds and cores. Sizes range from 919 to 1328 mm. long × 389 to 514 mm. wide × 1650 to 1670 mm. deep with wall thicknesses 100 and 125 mm. Casting-pit practice and pattern handling are described. Core boxes are made of reinforced concrete. A ' pouring pit ' consisting of a cast iron mantle 14 cm. thick is placed in an open pit on a cast-iron plate so that about one-fifth of the cast iron ' pouring pit ' projects above the open pit top. The internal dimensions of the cast-iron pit correspond to those of the outside of the cement sand mantle. Cast iron covers 12 cm. thick are used. Pure silica sand, free from clay, is applied for making the cement sand. Cement sand needs no artificial drying. The absorption of water by the cement strengthens the sand. If clay is present it absorbs water during preparation. This water can be removed only by heating but, as there is no heating of cement sand, the water remains in the sand and may give rise to a dangerous production of steam during pouring.—R. S.

Car Engine Piston Rings Cast Centrifugally in the Form of Sleeves. P. Januszewicz. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 270–277). [In English]. The cooling rate when centrifugal-casting sleeves in permanent moulds depends on : The pouring temperature of the cast iron ; die temperature at pouring ; wall thickness and thermal conductivity of dies ; coating ; temperature of cast sleeve on ejection from die ; and cooling conditions of cast sleeve. The difficulties in obtaining the proper structure are discussed. Casting trials, using water-cooled permanent dies, uncooled moulds and permanent moulds coated with a core sand layer 10 mm. thick, are described. In the first two series of trials (with a 1-mm. layer of dry silica sand) the graphite structure was unsatisfactory. The third method produced uniformly distributed lamellar graphite which was the structure desired.—R. S.

New Methods Produce Permanent Molds. G. A. Robinson. (Iron Age, 1950, vol. 166, Sept. 28, pp. 82–84). Metal-spraying processes for producing permanent moulds at low cost are being used at Northrop Aircraft Inc. These moulds and dies may be constructed of metal which develops a wearing surface of about 57 Rockwell C with a backing metal which can be easily machined. The process of building up a mould is described and it is stated that small patterns up to 1·5 sq. ft. of surface may be produced in two days by one man. Sprayed metal moulds have been produced that will withstand temperatures up to 2900° F.—A. M. F.

Symposium on the Metallurgy of the Internal Combustion Engine. Part II—Metallurgical Aspects of Cylinder Assemblies. L. G. Russell. (Australian Institute of Metals : Australasian Engineer, 1950, Oct. 7, pp. 76–84). The author gives a brief description of the methods of manufacture of cylinder liners, pistons, piston rings, and gudgeon pins, together with a detailed study of the metallurgical properties required in these various components. Comparison is also made between the different materials which are used in the manufacture of similar parts.—P. M. C.

Production of Massive Castings and Forgings at the Parkhead Works of William Beardmore and Co., Ltd. A. R. Parkes. (Iron and Coal Trades Review, 1950, vol. 161, Sept. 1, pp. 417–425 ; Foundry Trade Journal, 1950, vol. 89, Nov. 30, pp. 439–447). The Parkhead Works of William Beardmore and Co., Ltd., specializes in the manufacture of massive castings and forgings, producing castings of up to 120 tons finished weight and forgings ingots of up to 165 tons. A brief description of the post-war modernization and the general works layout is given, more detailed attention being given to the melting shop, foundry, pattern shop, machine shops, and laboratories. Examples of moulding and teeming procedures for large castings are given, and the fettling and subsequent heat-treatment of the castings are described.—G. F.

Materials Handling in Jobbing Foundries. J. J. Manders and H. R. Bruce. (International Foundry Congress, 1949, Metalen, Congress Issue Part II, pp. 253–269). [In English]. The materials-handling characteristics in mass production, in series (discontinuous production of a wide variety of products for rather long runs), and jobbing foundries are discussed. A general time-study scheme is considered and hints are made for lowering of production costs, improving quality, and obtaining better working conditions and greater safety.—R. S.

The Temperature of Liquid Steel in Relation to Fluidity and Sand Burning-on for Steel Castings. A. J. Zuithoff. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 184–197). [In English]. The factors affecting

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the fluidity of liquid steel are discussed. The following testing methods are compared: Wedge test, spiral test, pipe test, and grid test. The Sipp spiral test and the Ruff pipe test (slightly modified) were used by the author. It was found that the manner and exact moment of pouring overshadows all other factors affecting fluidity when samples were taken from the ladle. Tests taken from the bath of a 6-ton basic electric furnace showed better reproducibility. Temperature had the major effect on fluidity. Composition played a minor part. Too high a temperature gives good fluidity but causes burning-on of the mould dressing. The theory of burning-on is discussed. It is suggested that the mechanical penetration of fluid metal, following fusion of the grains, is a major cause of burning-on. Both fusion and metal penetration depend on the pouring temperature. Slight increase of temperature causes increased burning-on.—R. S.

Some Heat-Transfer Problems Simplified. J. S. Abcouwer. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 147–161). [In English]. The author suggests a fairly simple method for solving heat-transfer problems. The first part deals with mono-, bi-, and tri-dimensional heat transfer in an atmosphere of constant temperature. The equations are derived from, and compared with, known results (tables and graphs of Gröber, Williamson, and Adams are given). Some applications are described, including the drying and baking of cores. The second part deals with heat transmission in a two-body system. The thermal factors involved are first discussed and a law comparable to Newton's law of external cooling is sought. The following equation is used:

$$W = \frac{1}{\sqrt{\pi t}} \vartheta_0 t \frac{b_1 b_2}{b_1 + b_2}$$

where W is the heat flow in cal./sq. m./hr.; t is the time in hours; $\vartheta_0 t$ is the temperature at centre after t hours; b = heat susceptibility in cal./° C./m²h½. This formula is applicable to casting problems, both for sand and chill moulds and gives a relationship between the thickness of a casting and the specimen.—R. S.

Cracking and the Loss of Toughness and Strength of Grey Iron Castings. E. Jekerle. (Hutnické Listy, 1950, vol. 5, Nov., pp. 441–443). [In Czech]. Cracks, not detectable by the naked eye, in grey iron castings in Czech foundries were found to be due to the use of iron from blast-furnaces driven at a high production rate.—E. G.

Time Study in Foundries. H. W. Ward. (Foundry Trade Journal, 1950, vol. 89, Dec. 7, pp. 473–478). A description is given of the application of time-study technique to rate fixing in foundries.—J. W. P.

HEATING FURNACES AND SOAKING PITS

Radiant Furnace Speeds Billet Heating. H. Chase. (Iron Age, 1950, vol. 166, Sept. 21, pp. 100–101). Exceptionally fast heating of billets is attained in a barrel-type, radiant heating furnace at the new forge plant of the Ford Motor Co., Canton, Ohio. Tangential burners are fed with air and gas at 2 lb./sq. in. and the burning mixture revolves rapidly, hugging the walls of the combustion chamber. The flame thus does not impinge on the billets, and this, together with the rapid rate of heating, keeps scale formation to a minimum.

A. M. F.

Results from Structural Alterations to a Slab Reheating Furnace. O. J. Stebel. (Stahl und Eisen, 1950, vol. 70, Sept. 14, pp. 836–840). Structural alterations to a slab reheating furnace are described. These included additional heating in the roof, and insulation of the furnace and hearth; they led to a much improved heating of the slabs with a 40% reduction in heat required. Of particular advantage was the incorporation of an efficient valve system to prevent a fall in temperature during off periods. This prevented a loss of heat (*e.g.*, over the week-end) equivalent to 10 million kilocalories.—J. P.

Methods of Conveying in Electric Furnaces. J. McDonald. (Metallurgia, 1950, vol. 42, Aug., pp. 133–135). A description is given of the consolidation of information and design which has taken place recently in three types of electric furnace conveying mechanisms, namely: (*a*) Walking-beam furnaces; (*b*) flash annealing wire-rope furnaces; and (*c*) shaker-hearth furnaces. Amongst the problems discussed are the types of stainless ropes for use in the second of these, and the difficulties of ensuring a closely regulated time/temperature cycle using the last of these mechanisms.—J. J.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Principles of Heat Treatment. J. S. Vatchagandhy. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 23–50). The author discusses briefly the objects of heat-treatment and the general principles of the subject, with special reference to the iron–carbon system. The application of these principles in the manufacture of products together with other factors arising are considered. Various forms of annealing are described and particular attention paid to hardening, quenching media, and quenching cracks. The reasons for tempering and its advantages are given and case-hardening and case-carburizing discussed. **S**-curves and their applications, together with a brief reference to austempering and martempering, are considered.—D. H.

Some Notes on the Hardening and Heat Treatment of Steel. G. H. Jackson. (Transactions of the Institute of Marine Engineers, 1951, vol. 63, Jan., pp. 1–16). The author presents in fairly simple form the metallurgical principles involved in heat-treatment with the object of assisting engineers by giving sufficient fundamentals to enable heat-treatment of iron and steel to be more clearly understood. As a natural sequence to the behaviour of carbon in iron, the influence of other elements is discussed.—R. A. R.

Heat Treatment of High Speed Steels. P. H. Tata and K. N. P. Rao. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 165–183). The paper deals in some detail with the scientific understanding of the changes that take place during the heat-treatment processes with particular reference to high-speed steels. An attempt is made to present the latest available information on deviations from conventional practice.—D. H.

Heat Treatment of Two Commercial Tool Steels. S. Visvanathan. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 147–164). Details of the heat-treatment of coinage die steel and tap steel are given. More attention is paid to practical details peculiar to the manufacture of these steels than to the general principles involved. The preparation of a coinage die is briefly described and the factors affecting composition given. Particular reference is made to the hardening of Tata's mint die steel, and graphs are given showing the effect of hardening temperature on maximum surface hardness and hardness penetration. Details are given of the manufacture and chemical composition of a typical tap steel, Tata's tap steel typifying the low-alloy tungsten type. Hardness penetration curves for such a steel are given and the effect of tempering temperature on hardness is shown.—D. H.

Heat Treatment of High Speed Steel Tools. R. C. Stockton. (Machinery, 1950, vol. 76, June 1, pp. 778–782). The author discusses heat-treatment and mentions briefly the effects of tungsten, chromium, molybdenum, and vanadium with a carbon composition between 0·5 and 1·3%. The advantages of salt baths are rapid heat transfer, surface protection against scaling, and ease of checking temperature; reasonable variation in hardening temperature is permissible. He describes the Efco-Ajax Hultgren twin-electrode salt bath for three stages of treatment, preheating, high temperature, and secondary hardening. Post-hardening treatment by nitriding the finished hardened and ground tools can also be carried out in this equipment using a special cyanide-rich salt acting as the nitriding agent. Good performances have been recorded with a nitrided skin up to 0·002 in. deep; this treatment is not, however, universally applicable. For firms hardening only a few tools per week, an Efco-Sentry electric muffle furnace is described. This furnace has a replaceable carbon muffle which burns slowly, thus providing the furnace atmosphere. The resulting hardened tool has a mat grey finish.—T. W. H.

Modern Heat-Treatment Furnaces. L. G. A. Leonard. (Manchester Association of Engineers: Foundry Trade Journal, 1951, vol. 90, Jan. 25, pp. 89–94; Metal Treatment and Drop Forging, 1951, vol. 18, Jan., pp. 25–32). *See* Journ. I. and S.I., 1951, vol. 167, Mar., p. 341.

Equipment for the Heat-Treatment of Steel. R. A. P. Misra. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 253–278). Improvements in furnace design are traced with the development of various fuels and their advantages and disadvantages. The question of protective atmospheres

in furnaces is discussed with special reference to decarburization. The development of a new and simple type of atmosphere generator for which the author is responsible, is described in some detail and test results on steel of various compositions are given. Other outstanding developments in design such as the forced air circulation furnaces, gas-carburizing furnaces, and automatic hardening furnaces are discussed. The development of salt baths, both fuel-fired and the electrically heated types, is traced.—D. H.

The Pittsburgh Commercial Heat Treating Company. J. C. McComb. (Steel Processing, 1950, vol. 36, Oct., pp. 517–523). This company performs all major types of metal heat-treatment on a long or short run basis. The furnaces, salt baths, flame-hardening machines, and induction heaters are described and illustrated.—P. M. C.

FORGING, STAMPING, DRAWING, AND PRESSING

Forging Economies through Die Design. L. F. Spencer. (Iron Age, 1950, vol. 166, Sept. 7, pp. 99–103; Sept. 14, pp. 89–91). In the designing of forgings, the fundamental considerations are, draft angles, fillets, corners, shrinkages, and dimensional tolerances. Standard tolerances condensed from the Drop Forging Association standards are given for forgings up to 100 lb. and this article explains how to simplify die designs in order to achieve balanced sections. The selection of proper die material for wear resistance is stressed and 30 die steel types with the contents of alloying elements are listed.—A. M. F.

Die Sinking for Drop Forging. J. Mueller. (Steel Processing, 1950, vol. 36, Feb., pp. 76–79; May, pp. 234–237; Aug., pp. 398–401; Nov., pp. 567–569, 582, 583). Conclusion of a series of articles, *see* Journ. I. and S.I., 1950, vol. 165, July, p. 352. Part VII describes the basic steps in drop forging; fullering, edging, drawing, bending, roughing, and finishing. Several steps may be accomplished by one pair of die blocks having different impressions. Edging, roughing, and finishing are often done by one pair. Illustrations of three complex dies are shown. Part VIII deals with corner radii, fillets, and draft angles, and discusses the correct design and shape of die to facilitate easy metal flow. The edging, roughing, and finishing die stations for a single-throw crankshaft, a connecting rod, and a ring forging are shown. In Part IX the author describes locked dies—those having an irregular parting line. The points to watch when designing such dies are discussed. The final Part X outlines the design requirements for hot and cold trimmer dies and punches.—P. M. C.

The Use of Resilient Pads on Forging Hammers. F. A. Westbrook. (Steel Processing, 1950, vol. 36, Nov., pp. 565–566, 586). The author describes the use of a new resilient material, which materially reduces hammer vibration both in neighbouring shops and in the framework of the hammer itself. The material, called 'Fabreeka,' is made of tightly twisted, closely woven light duck, impregnated with a rubber compound. Pads of Fabreeka, placed above and below the usual oak foundation timbers and also between the yoke, frame, and anvil of the hammer itself, markedly reduce vibration and shock.—P. M. C.

The Cornell Forge Company. (Steel Processing, 1950, vol. 36, Oct., pp. 499–503). This is a short description of the products, equipment, plant layout, and operating sequences at the Cornell plant, Chicago. The company, which specializes in light precision forgings, moved to its present well-designed plant in 1945, and its ten modern hammers use about 600 tons of ½-in. to 3-in. round bar stock per year.—P. M. C.

Up-to-date Heavy Forging Shops. A. Terény. (Bányászati és Kohászati Lapok, 1950, vol. 5, Nov., pp. 622–633). [In Hungarian]. The power requirements of heavy forging machines and the reasons for the extensive application of hydraulic controls are dealt with. Information is given on heavy presses available in several countries (including U.S.S.R. and Czechoslovakia) in 1945. Different hydraulic drives are described and compared.—E. G.

A Swedish Technician's Comments on the American Drop Forging Industry. B. Lagercrantz. (Metal Treatment and Drop Forging, 1950, vol. 17, Autumn Issue, pp. 164–166). The author has visited a number of American forges, and gives his brief impressions of conditions, techniques, and production methods. He expresses admiration for the British productivity teams' reports, and indicates some of the differences between American, British, and Swedish forges.

P. M. C.

Production of Bolts and Nuts. A. P. Newall. (West of Scotland Iron and Steel Institute, Jan., 1951, Preprint). The paper reviews the development of mass-production methods of bolt and nut manufacture, especially by cold upsetting or hot forging. Some comments are made on the physical and metallurgical characteristics required in the material. Finally, mention is made of the recent application of high-frequency heating in forging and heat-treatment.—R. A. R.

Presswork Production—An Examination of the Technique of Using Progressive Tools. R. Kirchner and G. V. Bevan. (Sheet and Strip Metal Users' Technical Association: Sheet Metal Industries, 1950, vol. 27, Oct., pp. 851–870). Progressive tools may be used to produce many simple components from strip, which would otherwise require several operations. The authors give detailed illustrations and operating sequences for the following typical tools: A simple three-stage progressive tool; a double cut-off and form tool for continuous strip feed; a four-stage tool with transfer feed; a 12-stage progression tool; a nine-stage tool for extra thin material (0·006-in. nickel); a progression tool with self-contained feed, and tools for progressive shallow and deep drawing. The uses of multislide presses are briefly outlined.—P. M. C.

Stamping Deep Drawn Parts at Transue-Williams. J. C. McComb. (Steel Processing, 1950, vol. 36, Oct., pp. 491–498). This is a general description of the products, equipment, plant layout, and operating sequences at the Stamping Division of the Transue and Williams Company (U.S.A.). The plant has 34 presses, and uses 750 tons of low-carbon steel sheet per month. The main products are oil sumps for internal combustion engines.—P. M. C.

The Cold Working of the Stainless Steel. L. F. Spencer. (Steel Processing, 1950, vol. 36, Aug., pp. 383–391, 397; Sept., pp. 440–446; Oct., pp. 504–509; Nov., pp. 570–575, 587). In Part I, the properties and suitability for cold working of the three types of stainless (austenitic, ferritic, and martensitic) are briefly outlined, and the seven standard surface finishes are specified. Then follows descriptions of blanking, punching, trimming, and perforating. Part II deals with bending operations. Continuous draw rolling and cold roll forming of strip are first described, followed by the use of the press brake and the Guerin process. Shallow and deep drawing are dealt with in Part III, particular attention being paid to tool design, drawing sequences, and choice of material. In Part IV, spinning and cold heading are briefly described, and the choice of lubricants, tool materials, and pressing equipment is discussed. The series is well illustrated with diagrams of drawing and forming operations, and with photographs of equipment. There are 16 references.—P. M. C.

Allegheny Ludlum Analyzes Drawing Characteristics of Stainless Steels. R. H. Henke. (Steel, 1950, vol. 127, Sept. 4, pp. 88–90, 96–98). Austenitic stainless steels have a rate of work hardening far in excess of other metals and reach a much higher hardness. This paper discusses the drawing characteristics of a number of stainless types and points out that modifying the composition cannot make them draw like unalloyed steel but it can modify the effect of the high strength and high rate of cold-work hardenability.—A. M. F.

The Aluminium Bearing, Non-Aging Steels and Their Cold Extrusion. H. Hauttman and H. J. Pessl. (Steel Processing, 1950, vol. 36, Nov., pp. 557–564, 583). A minimum of 0·02% metallic aluminium, and a minimum cooling rate through the A_1-transformation range of 10° C./min., are necessary to secure a sufficiently high ageing resistance and to guarantee the ductility and notch toughness required for successful cold extrusion. The physical properties and their dependence upon cooling rate are quoted for typical steels. A brief outline of the process is given; die angles are usually of the order of 125°, reductions in area up to 90% may be obtained, and phosphate or zinc coatings are the most satisfactory lubricants.—P. M. C.

A Practical Consideration of the Heating of Carbon Steel Rod and Wire in the Patenting Process. W. R. Bloxdorf. (Wire and Wire Products, 1950, vol. 25, Nov., pp. 965–969, 1002–1004). The author provides data in the form of curves, from which one can calculate the correct speed of travel of a carbon wire through an open-fired patenting furnace, in order that the wire may be uniformly heated to the furnace temperature. The curves are based on small-scale experiments, and their value has been confirmed by full-scale tests in which the criterion was conformity of structure.—J. G. W.

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The Problem of Die Wear with Special Reference to the Performance of Sintered Carbide Dies. J. G. Wistreich. (Wire Industry, 1950, vol. 17, Nov., pp. 889–892, 895–899). In the first part of the paper the author draws attention to the economic importance of the die problem, which should be gauged not by the cost of dies, but by the machine hours lost as a result of die changes. Figures quoted range from 6 to 15% of the working time. These figures can be improved upon, without the necessity for improving dies, by judicious timing of individual die changes, by proper co-ordination between die issue department and machine operative, and by a suitable design of die-holding fixtures. In the second part of the paper B.I.S.R.A. research into the nature of die wear is reviewed. The author points out that on account of the great variability of die performance in wire mills, works tests are of little value if based on less than 40 dies. 'Ringing' is described by reference to profiles and to microsections of worn dies, and experimental evidence is quoted in support of the theory that 'ringing' is caused by stress concentration near the point of contact between wire and die wall, and that it can be mitigated by the application of back pull. Experimental results support the belief that roughing dies open out more slowly if the sizing portion consists of a short parallel section, and the bad effect of misalignment between wire and die both at entry and exit is demonstrated from experiments. The use of a centring nozzle at entry is suggested. In the discussion of the paper the following topics are raised: Thermal shock in tungsten carbide dies arising from water cooling of the dies in high-speed machines; the value of a high polish in dies; and the effect on die life of mechanical descaling of the wire, and of phosphate coating.

Ringing in Wire-Drawing Dies. J. G. Wistreich. (Journal of The Iron and Steel Institute, 1951, vol. 167, Feb., pp. 162–164). 'Ringing,' which is a form of grooving of dies near the point of entry of the wire, is an undesirable phenomenon, the suppression of which might result in better die performance. It is concluded from experiments that, generally, ringing is not caused by the abrasive action of a contaminated lubricant, but is the result of the steep stress gradient at the beginning of the working surface of the die. For this reason ringing cannot be altogether suppressed, but it is possible greatly to reduce its severity by applying heavy back pull to the wire.

ROLLING-MILL PRACTICE

Developments in the Design of D.C. Motors and Generators for Rolling Mills. B. H. Caldwell, jun. (Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 63–71). The advances in rolling-mill technique and the increase in delivery speeds of cold strip mills have challenged the designers of D.C. motors and generators. This article deals with some of the important developments which have been made in the design of such equipment. Requirements and performances of rod and tube mill motors are discussed, and the need for very close synchronization of relative motor speeds in tandem mills is stressed. Diagrams are given illustrating the fundamental behaviour of D.C. motors driving individual stands of a continuous mill; impact speed drop is given as a function of time constant and as a function of rating and size. The following motor design constants contributing to good performance in tandem cold strip mills are discussed in detail: Motor inertia; ohmic drop in the armature circuit; steady-rate speed regulation, and lastly the degree to which the transient and steady-rate characteristics are matched. The developments of control devices, which have led to improved operation of fast reversing application as on slabbing and blooming mills, are also described.—M. D. J. B.

New 42-in. Slabbing Mill at Shotton. (Iron and Coal Trades Review, 1950, vol. 161, Dec. 8, pp. 869, 873: Engineering, 1951, vol. 171, Jan. 5, pp. 1–5). **New Slabbing Mill at Shotton.** (British Steelmaker, 1951, vol. 17, Jan., pp. 14–17, 20: Metallurgia, 1950, vol. 42, Dec., pp. 397–399). The recently installed 42-in. reversing slabbing mill at Messrs. John Summers and Sons, Ltd., Shotton, is designed to accept a maximum ingot size of 15 tons, and is expected to have an ultimate output of 20,000 tons/week when the extensive enlargements to the steelmaking capacity of the works are completed. The design and operation of the mill are described in some detail, and a brief indication of future expansion at the works is also given.—G. F.

The Midland Works of Crucible Steel Co. of America. T. J. Ess. (Iron and Steel Engineer, 1950, vol. 27, Oct., pp. M1–M19). A detailed description is given of the Midland Works of Crucible Steel Co. of America. Starting with a historical note, statistical information on the plant, consumption, and production, is given. Information is also given on the steel-making units which comprise 11 stationary 135-ton open-hearth furnaces and six electric arc furnaces. Steel is produced in a wide variety of carbon and high-quality alloy grades. The rolling mills, described in detail, comprise a 40-in. two-high reversing blooming mill and three finishing mills providing facilities for a broad range of bar sizes. These are a 24-in. bar mill producing rounds, squares, and flats, a merchant mill combining continuous looping and cross-country layout, and an 18-stand 12-in. cross-country mill reducing 4–6-in. square billets to a wide range of rounds, squares, flats, and hexagons. Details are also given on reheating furnaces, and heat-treating, annealing, and cold-finishing facilities for bars and rods. Special attention is drawn to the new four-high reversing hot strip mill, designed to give flexibility and to the tandem cold mill which has a capacity of 4000 tons/month of stainless steel strip in widths ranging from 18 to 50 in.—M. D. J. B.

Rolls and Rolling. E. C. Brayshaw. (Blast Furnace and Steel Plant, 1949, vol. 37, Apr., pp. 435–441; May, pp. 543–549; June, pp. 698–704; July, pp. 821–830; Sept., pp. 1069–1077; Oct., pp. 1212–1222, 1231, 1232, 1253; Nov., pp. 1341–1349, 1353; Dec., pp. 1456–1462; 1950, vol. 38, Feb., pp. 196–206; Mar., pp. 322–330). Continuation of a series of articles (*see* Journ. I. and S.I., 1949, vol. 162, Aug., p. 484). The author describes various types of 'ragging' (cutting grooves in rolls to make them bite) for the rolls of a blooming mill, and then explains a number of methods of rolling in the three-high mill, including the use of diamond passes. He then goes on to the cross-country billet mill and the continuous billet mill, which he considers the most efficient producer of billets; box-pass methods and diamond–square methods are described. He next considers the production of merchant bars, the series of passes employed being oval–square–oval, diamond–square–oval, diamond–diamond–diamond, flat–edge–flat, or oval–round–oval; their several advantages are discussed. He then deals with various methods of producing rounds from earlier shapes, such as the oval–square–oval, diamond–square–diamond, and the use of octagonal passes for very large rounds. The re-rolling of rails, and the production of rounds from the separated parts (head, web, and flange) and the special rounds such as corrugated concrete-reinforcing bars are next treated. The production of hand rounds is dealt with at some length, including the use of three-high roll sets. The author next deals with the production of squares, and describes various ingenious methods, involving the use of box-passes in earlier stages before passing on to diamond and diamond–oval–diamond passes. The use of rectangular billets as a basis for squares is also noted. The rolling of hexagons is next dealt with: here there are two possible methods, the point, where the diagonal of the hexagon is at right angles to the roll axis, and the flat, when the diagonal, and therefore two flats, are parallel to the roll axis. Passes for both methods are illustrated. In the rolling of octagons, the flat method is universally employed: the rolling of these from squares is illustrated. In the rolling of flats, tongue-and-groove methods are largely used except for edging passes; the advantages of using a fluted square are discussed. The rolling of 'near square' flats, *i.e.*, those down to say $\frac{1}{4}$ in. by $\frac{11}{32}$ in., nut flats for example, is not a simple operation, and may also be done from fluted squares; diagonal rolling is also of use. This section of the series also includes the description of passes for rolling both wide and narrow flats, and an ingenious design of a series of passes for rolling a complete rail section down to a wide flat.—J. P. S.

Some Considerations on the Rolling of Ovals before the Rolling of Small Rounds, 5–10 mm. in Diameter. F. Del Moral. (Metalurgia y Electricidad, 1950, vol. 14, June, pp. 142–143). [In Spanish]. The author explains his theory that the optimum size of oval for rolling 5-mm. dia. rods is $7{\cdot}5 \times 3{\cdot}5$ mm.—R. S.

Electrical Equipment for Billet, Structural, and Rail Mills. C. C. Thomas. (Blast Furnace and Steel Plant, 1950, vol. 38, May, pp. 541–553, 560, 561, 580, 587). The author discusses the problems involved in the application of electrical

equipment to a typical example of each type of billet, structural, and rail mill.—J. P. S.

Rolling Flats with Corrugated Passes. A. Lhermitte. (Blast Furnace and Steel Plant, 1950, vol. 38, Apr., pp. 423–426). The rolling of flats and strips by the methods used with corrugated passes is described. The operations considered are the rolling of $4\frac{5}{32}$-in. and $3\frac{11}{32}$-in. strip bars; the rolling of 6-in. sheet bar section; the rolling of $7\frac{13}{16}$-in. strip, and the rolling of $15\frac{1}{2}$-in. strip on a 28-in. structural mill.

J. P. S.

Production of Bars. C. W. Barrett. (Steel, 1950, vol. 127, Aug. 7, pp. 94–106; Aug. 14, pp. 94–100). The author gives descriptions of the various types and arrangements of mills that are used for the production of bars. The methods of producing special sections are discussed and the difficulties involved in such work are stressed.—A. M. F.

New Bar Production Facilities at Bethlehem's Lackawanna Plant. G. A. Henderson. (Iron and Steel Engineer, 1950, vol. 27, Nov., pp. 93–100). This article describes in detail a new 10-in. continuous, high-speed merchant bar mill put in by the Bethlehem Steel Co. to modernize their bar production facilities. The mill has been specially designed to improve the quality of the product and attention has been paid to the following features: Careful control of all heating operations, from soaking pits to bar-mill furnaces; surface preparation of billets, preceded by complete skinning of blooms in the hot scarfing machine; design of guides and loopers to avoid scratching of bars between passes; elimination of twisting and deflections of billets and bars in rolling mills by using alternate horizontal and vertical stands; high rolling speeds to minimize the temperature drop; adequate facilities for controlled cooling; and the latest equipment for the heat-treatment of bars both in coils and in straight lengths. Both technical and operating details of the above-mentioned features are fully described.—M. D. J. B.

Les Forges de Strasbourg. Duval. (Mémoires de la Société des Ingénieurs Civils de France, 1949, vol. 102, Aug.–Sept.–Oct., pp. 476–478). A brief account is given of the plant and products at the Port du Rhin works of the Forges de Strasbourg. Producer-gas-fired reheating furnaces are used to heat sheet bars for rolling into sheets up to 3 mm. thick. There is also a pickling and galvanizing plant. Production is 8000 tons/month.—R. A. R.

Chile Builds a New Merchant Mill. E. C. Peterson. (Iron and Steel Engineer, 1950, vol. 27, Nov., pp. 88–92). This article describes a mill developed and manufactured for Chile by H. A. Brassert and Co. and Koppers Co. It is capable of relatively high tonnage production, with a minimum of hand labour and a variety of product that would normally be produced on three speciality mills. Details of the mill layout are given. The mill comprises an 18-in. three-high two-speed mill, a five-stand 14-in. mill, a two-stand 12-in. mill, a two-stand 10-in. mill with repeater, and a six-stand 10-in. continuous rod mill. The 14-in. and 12-in. mills are of the cross-country design. The general arrangement of the mill is made around a standard Belgian mill. A description is also given of the handling equipment, cooling banks, and straightener for sections.—M. D. J. B.

Rationalization of the Production Programme of Rolling Mills by Reducing the Number of Sections in It. L. Szeless. (Bányászati és Kohászati Lapok, 1950, vol. 5, Nov., pp. 617–621). [In Hungarian]. Factors affecting the output of Hungarian rolling mills are investigated and the increase in output resulting from concentration of production to a smaller number of types of section is reported.—E. G.

An Analysis of Some Roll-Pass Designs for Round Sections. D. A. Winton. (Journal of The Iron and Steel Institute, 1951, vol. 167, Jan., pp. 31–41). Schedules of roll passes for reducing billets to round sections have been analysed and compared. The square–diamond and the oval–square sequences require fewer passes than other sequences to reduce a billet to any particular size of round. An approximate relationship exists between the area per pass, the number of passes preceding it, and the billet area. The leader pass is found to be nearly elliptical in shape, and curves are given from which leaders may be constructed for any size of round up to 5-in. dia. The design of the finishing pass is also discussed. Details of the rolls and mills used are given in an appendix.

Cold Rolling of Tinplate. G. E. Stoltz and J. W. Brinks. (Iron and Steel Engineer, 1950, vol. 27, Oct., pp. 69–77). The progress in delivery speeds of tandem cold tinplate mills over the last 20 years is reviewed and a test carried out on a high-speed mill at the Weirton Steel Co. is described. In co-operation with the Westinghouse Electric Corp. records were obtained of kilowatt input to the motor-generator sets, motor armatures' ampères, and voltage, speed, and roll pressure of each stand, as well as tension between stands and strip thickness out of No. 1 and No. 5 stands. General-arrangement drawings of the electric drives are given as well as power requirements and graphical representation of the cold-mill performance. Over-gauge and the causes of over-gauge are discussed. Strip thickness is studied in relation to delivery speeds, and oil-film thickness in relation to viscosity and temperature. The trend towards larger coils as delivery speeds increase is considered.—M. D. J. B.

Strip Rolling Mill. (Engineer, 1950, vol. 190, Oct. 6, pp. 345–347). A description is given of a four-stand tandem strip rolling mill designed for the high-speed cold rolling of high-carbon and stainless-steel strip. The mill, built by Sir James Farmer Norton and Co., Ltd., was delivered to Sweden. The plant is designed to handle coils of 10-in. wide strip up to one ton in weight and to roll them down to thicknesses from 0·140 to 0·105 in. An interesting method has been developed for indicating the tension of the strip in which only the fourth stand is securely tied, the three preceding stands being mounted on steel rockers permitting a few degrees of rocking motion in the direction of rolling. General layout drawings and illustrations of the mill are given as well as details of roll balancing, the cooling system, the coiler drum, the control switches, and the four main mill motors.—M. D. J. B.

"English Electric" Equipment in the Wide Hot Strip Mill of John Summers and Sons Ltd., Shotton, nr. Chester. G. R. Wilson. (English Electric Journal, 1950, vol. 12, Dec., pp. 11–18). An illustrated description is given of the electrical equipment at the above hot strip mill. With the exception of the vertical scale-breaker driven by two 300-h.p. induction motors, all the stands are four-high. The roughing stands consist of a spreader stand driven by an induction motor, and two universal stands each driven by 2500-h.p. synchronous motors. There are five finishing stands with 22-in. dia. work rolls, four driven by 300-h.p. motors and one by a 2000-h.p. motor, all D.C. For mild-steel production the consumption averages 60 kWh./ton.—R. A. R.

Limits of Pack Thickness in the Rolling of Thin Sheets. E. Günther. (Die Technik, 1950, vol. 5, Mar., pp. 109–111). The thickness of sheet parcels is an important factor in the output of thin sheet mills. It cannot, however, be chosen without regard to technical considerations. In the case of very thin sheet, thick parcels make even heating difficult. The maximum thickness depends on the capacity of the heating plant. Other limitations are imposed by the shape and minimum width of the roll gap when the rolls are hot. Finally, the weight of thick parcels introduces handling problems which are solved satisfactorily only in fully mechanized mills.

J. G. W.

The Causes of Sticking in the Rolling of Thin Sheets. E. Günther. (Die Technik, 1950, vol. 5, Apr., pp. 201–202). The author argues that apart from the condition of the sheet, *i.e.*, its surface, composition, and temperature, the actual rolling conditions are chiefly responsible for the sticking of sheets and the splitting of the sheet parcels. In particular, if the roll gap is not of the right shape, or the rolls in a two-high mill not properly aligned, the roll pressures are not properly distributed. As a consequence an appreciable flow of the material in a direction at right angles to the direction of rolling occurs close to the neutral point, causing sticking. An increase in roll friction caused by a deterioration of the roll surface can lead to similar results.—J. G. W.

Flat Rolled Steel on the Pacific Coast. O. L. Pringle. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 252–262). The development of the steel plate and sheet industry on the American Pacific Coast is discussed, and descriptions are given of the plate mill and finishing facilities at the Geneva Steel Co. and of the sheet mills and tinning units at the Pittsburgh Works of Columbia Steel Co.—G. F.

XUM

Packaging Flat Rolled Steel. C. E. Miller. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 134–160). The various methods of handling, packaging, and loading flat rolled steel products are briefly described, and illustrations are presented showing typical packages and loads of plates, sheets, strip, tinplate, and stainless steel sheets.—G. F.

Packaging Coiled Strip and Wire. H. F. Jacobsen. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 103–110). Modern methods of handling and packaging light steel products are described, particular attention being given to strip and wire coils. The importance of careful handling and packaging of the finished product is emphasized.—G. F.

Hot-Strip Rolling Mills. J. Malborn. (Sheet Metal Industries, 1950, vol. 27, July, pp. 581–594, 596). After giving a brief summary of the evolution of the modern 4-high mill, the author reviews the present-day types and gives details of plant layouts and operating data. The three types of mill, fully continuous, semi-continuous, and Steckel, are dealt with separately. Auxiliary equipment is fully described. Tables are also included which show general ranges of strip thicknesses and widths which can be produced by different types of mill. P. M. C.

McLouth: Unconventional Strip Supplier. (Steel, 1950, vol. 127, July 17, pp. 62–63). The new McLouth Steel Corporation plant at Trenton, Michigan, is turning out 400,000 tons/annum of strip. The plant is unconventional in that the slabbing mill reduces 26 × 44 in. ingots to $\frac{5}{8}$ in. and strip for automobiles is produced in a reversing four-high mill without reheating.—A. M. F.

Cold Rolling Mills—Considerations Involved in Their Selection. L. R. Underwood. (Sheet Metal Industries, 1950, vol. 27, Apr., pp. 293–306, 308). This article considers the general principles governing the selection of a mill to carry out a specified rolling programme. The relative merits of tandem and single stand, two-high and four-high, and reversing and non-reversing mills are first outlined, followed by a survey of the factors governing the choice of roll size, rolling speed, main mill drive, and screwdown gear. Different types of coiler gear are also fully dealt with, and the application of the new Vickers-Armstrong hydraulic variable-speed gear drive to a reversing strip mill is explained. Three special types of mill, which have been designed to reap the advantages of small diameter work rolls, are described. These are the Sendzimir, the Steckel, and the American **Y** mills.—P. M. C.

Cold Roll Forming. E. J. Vanderploeg. (American Society of Tool Engineers: Metal Industry, 1950, vol. 76, May 19, pp. 399–401, 406; Steel, 1950, vol. 126, Apr. 24, pp. 81–84; May 1, pp. 91–93). Cold roll forming is a process in which a flat metal strip, by passing through a series of rolls arranged in tandem, is progressively formed into the ultimate desired shape. The author describes types of machine, classes of work that can be undertaken, limitations of the process, and the design of rolls and roll sequences.—P. M. C.

The Manufacture of Hot-Rolled, Hot-Finished Steel Tubes. J. Porteous. (Australasian Engineer, 1950, Sept. 7, pp. 74–79). The author describes in detail the manufacture of tubes by the continuous butt-weld process, and by various seamless methods. In the former case, flat strip is heated to about 1350° C. and then passed into a multi-stand mill. Here the strip is formed into a tube, the edges are welded together, and reduction to the required size is accomplished. The seamless methods can all be divided into two distinct operations, piercing and elongation, each of which can be accomplished by rotary or non-rotary methods. The Mannesmann, Stiefel, and cone piercers (all rotary) are briefly described, and reference is made to the Pilger, Foren, and Diescher rotary elongating mills. Non-rotary piercing is usually accomplished on a hydraulic press, the hollow cylinder then produced being elongated by passing through a train of dies. Extrusion methods are also referred to.—P. M. C.

American Seamless Tube Mill. (Engineer, 1951, vol. 191, Feb. 23, pp. 249–250). **National Tube Starts Operation of New Tube Mills at Gary.** (Iron and Steel Engineer, 1950, vol. 27, July, pp. 123–128). **New Gary Mill Processes both Seamless and Welded Tubing.** (Steel, 1950, vol. 127, July 3, pp. 94, 97, 98, 100). **Seamless Tubes Now Produced at Modernized Gary Works.** (Blast Furnace and Steel Plant, 1950, vol. 38, Sept., pp. 1035–1039). This paper describes a new mill for the National Tube Co. going into service at the Gary Works. The mill is an entirely new development and features continuous rolling on a mandrel and incorporates the stretch-reducing process in 12 separately powered stands. The facilities for rolling seamless tubes, electric welded tubes, and stainless steel tubes are described. Details are given of the finishing banks, the processing department, the metallurgical laboratory and also of the general services.—M. D. J. B.

New Push Bench at the Weldless Steel Tube Company Ltd., Wednesfield. (Iron and Coal Trades Review, 1950, vol. 161, Aug. 11, pp. 293–294). A brief description is given of the design and operation of the new push-bench tube mill installed at the works of the Weldless Steel Tube Co., Ltd., Wednesfield, for the production of hot finished seamless steel tubing. The machine has a size range from $2\frac{5}{8}$ in. to $3\frac{3}{4}$ in., and a maximum production rate of four tubes 22 ft. 6 in. long per minute.—G. F.

Automatic Self-Centering Rolls and Pulleys. E. T. Lorig. (Iron and Steel Engineer, 1950, vol. 27, Nov., pp. 57–67). A study is made of strip processing equipment with a view to improving the tracking and aligning of metal strip, reducing high concentrated detrimental strip tensions, and relieving or preventing damage to the strip by the apparent faulty guiding. A detailed mathematical analysis of conveyor rolls and the behaviour of strip has been made by the Carnegie Illinois Steel Corp. This study into the action taking place in conventional equipment has led to the solution of many problems and to the development of self-centring rolls. The steps taken to improve tracking are described as well as the development and functioning of automatic self-centring rolls. The action of metal strip in contact with rolls and the adverse effects of spring-loaded mountings as well as the construction of the rolls are discussed in detail. Finally, the author describes the applications of split automatic self-centring rolls.—M. D. J. B.

The Use of Roller Bearings in Hot Rolling Mill Housings. W. Krämer. (Stahl und Eisen, 1950, vol. 70, Oct. 12, pp. 925–929). Ten designs for the application of indirect roller-bearing supports for roll-necks are illustrated and their advantages discussed.—J. P.

Plate and Sheet Levelling Appliances: Factors in Design, Operation and Maintenance. F. A. Batty. (Iron and Coal Trades Review, 1950, vol. 161, Oct. 20, pp. 571–576). The author outlines some of the difficulties involved in levelling sheet, strip, and plate, and discusses the influence of these difficulties in the design and future development of levelling appliances. Problems of design, operation, and maintenance of roller levellers and roll-type coilers are also considered. G. F.

Budgeted Blooming Mill Maintenance. J. H. Mayer. (Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 90–92). This article describes budgeted maintenance for the rolling mills of the Pittsburgh Works of Jones and Laughlin Steel Corp. Budgeted maintenance consists of planning a programme established for budgeting time, materials, and labour in addition to money, with a view to decreasing operating delays, increasing production, and obtaining lower operating costs. A card system of drawing up inventories of spares is described. The difficulties encountered in setting up a maintenance budget to cover unusual expenses and contingencies are enumerated. The author concludes that although the budgeting of maintenance may be more difficult than routine production work, it is well worth doing.—M. D. J. B.

MACHINERY FOR IRON AND STEEL PLANT

Hot Bloom and Slab Shears. J. A. Kilby. (Journal of The Iron and Steel Institute, 1951, vol. 167, Feb., pp. 165–199). This paper is limited to a consideration of shears for the hot cutting of blooms and slabs more than 6 in. square and 18 in. wide × 2 in. thick, respectively. The subject is dealt with in broad outline only, and the main features of this type of equipment are reviewed.

Weighing Equipment in Iron and Steel Works. C. Jolas. (Stahl und Eisen, 1950, vol. 70, Aug. 31, pp. 768–774). After outlining the principles of the modern weighbridge, the types of weighing equipment (manual, automatic, and self-recording) for use in various parts of a works are described. These are for weighing ingots, tubes, bars, ore and coal wagons, and ladles for iron or steel.—J. P.

Dynamic Capacity of Rolling Bearings. G. Lundberg and A. Palmgren. (Ingeniörs Vetenskaps Akademien, 1947. Handlingar No. 196). [In English]. In this mathematical paper the foundation is laid for a unified theory of the dynamic capacity for rolling bearings. The theory is based on a statistical formula for the dispersion in life of bearings. By a suitable choice of exponents in the statistical formula it has been possible to obtain a satisfactory agreement between the theory and the experimental basis.—R. A. R.

The Friction of Adequately Lubricated Machine Parts Having Regard to a Rational Energy Economy. G. Vogelpohl. (Stahl und Eisen, 1950, vol. 70, Oct. 12, pp. 930–936). The importance of friction in machines is stressed by the fact that the gross annual cost in West Germany for lubricants, in energy lost through friction, and through wear, amounts to 3000 million marks. Although revolving bearings have proved to be an excellent solution in many instances, there are some in which plain bearings offer considerable advantages, particularly at high rotation speeds. It is, however, essential to use a lubricant which is suitable for the load and not too viscous. To demonstrate this, a test was conducted in which a high-speed shaft ran better with air than with oil lubrication or on a revolving bearing, though the last two showed less friction at low speeds. A simple graphical relationship between a generalized coefficient of friction and the Sommerfeld number is proposed as a basis for design and operation of plain bearings.—J. P.

Heavy Steelworks Diesel Locomotive. (Engineer, 1950, vol. 190, Dec. 22, p. 625). **Diesel Locomotives for Steelworks.** (Engineering, 1950, vol. 170, Dec. 8, p. 467). A description is given of a 40-ton, four-wheel, 300 brake h.p. diesel mechanical locomotive, ordered by the Consett Iron Co., Ltd., and constructed by the Hunslet Engine Co., Ltd., Leeds. The locomotive is specially designed for steelworks use, it is simple and robust and has a short 6 ft. 6 in. wheelbox capable of negotiating the small radii prevailing in works railway systems. Loads up to 1200 tons can be started and hauled in first gear and a train of 850 tons can be hauled at a speed of 6 m.p.h. The engine is a Crossley five-cylinder two-stroke oil engine developing 300 brake h.p. at 900 r.p.m. Constructional and operating details are given.—M. D. J. B.

Maintenance of Diesel Electric Locomotives for Switching Service. H. C. Jones. (Iron and Steel Engineer, 1950, vol. 27, Sept., pp. 98–107). The author describes the principal operations and tools necessary to keep the fleet of 33 diesel-electric shunting locomotives of the Patapsco and Back Rivers Railroad Co., Sparrows Point, Md., in good condition. The uses of a viscosimeter, a hot plate for detecting the presence of water in oil, and an electrophotometer to determine free carbon and oxidation are described. The grades of oil and nature of the water for the cooling systems are given. The layout and equipment of the locomotive maintenance shop are also given, as well as details of the maintenance carried out. This covers repairs to wheels, traction motors, to the diesel engines, piston repairs, rehabilitation of cylinder heads, valve guides, valves, connecting rods, bearings, and governors.

M. D. J. B.

Diesel Locomotive Maintenance Procedure. R. L. Baker. (Iron and Steel Engineer, 1950, vol. 27, Sept., pp. 94–96). Information on the permanent way and diesel locomotive fleet of the Union Railroad, East Pittsburgh, Pa., is given. The author then discusses in detail the monthly, quarterly, and half-yearly inspection and maintenance procedure. Both electrical and mechanical inspection are dealt with. The need for able maintenance personnel is stressed.—M. D. J. B.

Kembla's New Diesel-Electric Locomotives. (B.H.P. Review, 1950, vol. 18, Dec., pp. 18–19). Eight 85-ton 800-h.p. diesel-electric locomotives are on order for the Broken Hill Proprietary Co., Ltd. Two have been delivered and some particulars of these and the work they do are presented. They are to be used mainly to haul 60-ton coal trucks on a 5-mile railway between Neblo Colliery and the Kembla Works. Each locomotive can haul 3000 tons on a level track. The power unit consists of an 8-cylinder ' in line ' engine to which air is supplied to the inlet valves at slightly above atmospheric pressure ; this drives a 520-kW. generator which supplies four 135-h.p. 400-V. traction motors mounted one on each axle.

R. A. R.

Application of Industrial Control Relays. B. H. Carlisle, jun. (Iron and Steel Engineer, 1950, vol. 27, Nov., pp. 119–125). This paper describes the operation and applications of some of the more common types of industrial control relays. A brief review is first given of some of the basic characteristics of D.C. motors, after which the author describes the simplest of the special purpose relays, the field loss or field protective relay. This is followed by a description of field acceleration and field deceleration relays, no load, anti-plug, and plugging relays. Basic circuit diagrams are given and the operating characteristics and relative merits of the relays are discussed.—M. D. J. B.

Mechanical Handling in the Iron and Steel Industry. G. R. Bashforth. (British Steelmaker, 1950, vol. 16, June, pp. 281–292). The author reviews the development of mechanical handling methods used in the iron and steel industry, dealing with ore handling and preparation, blast-furnaces, Bessemer and open-hearth processes, casting bays, rolling mills, and general equipment. The necessity for careful maintenance in order to obtain successful continuous operation of the mechanical devices is emphasized.—G. F.

A New Form of Power and Steam Generation from Waste Heat. (Engineering and Boiler House Review, 1950, vol. 65, Oct., pp. 325–326). **Gas Turbine for a Waste Heat Recovery Installation.** (Engineer, 1950, vol. 190, Sept. 22, p. 295). This article describes a model of a waste heat recovery unit shown in the gas section of the exhibition 'Energy in the Service of Man' organized in connection with the British Association in Birmingham. The model shows the arrangement of a pioneer plant, incorporating a new system of waste heat recovery, developed by Spencer Bonecourt, Ltd., and ordered by the West Midlands Gas Board for installation at a gas works in the near future.—M. D. J. B.

Gas Turbines for Industrial Purposes. A. T. Bowden. (British Association: Engineer, 1950, vol. 190, Sept. 29, pp. 333–336; Engineering, 1950, vol. 170, Sept. 8, pp. 214–216). The author considers the development of the industrial gas turbine and the possibility that this type of prime mover may invade the fields held hitherto by the steam turbine and the diesel engine. The advantages and disadvantages of the gas turbine are briefly set out and the fundamental soundness of its operating cycle stressed. A comparison is made of the steam and gas turbine cycles and of the directions in which they have already moved and are likely to move in the drive for higher efficiencies. The author suggests that large industrial gas turbines lack the simplicity and potential cheapness of production of the smaller and medium units and are therefore lacking in those essentials which make this prime mover so attractive in comparison with other forms. The field for gas turbines of small or medium output is, however, most promising.—M. D. J. B.

High Tensile Bar Reeling and Shearing Machines. (Engineer, 1950, vol. 190, Aug. 18, p. 187). A description is given of the round bar reeling machine and the bar shears constructed at the Bronx Engineering Co., Ltd., Lye, Stourbridge. The machines are designed and built to deal with 'Nimonic' and other high-tensile steels at the works of Henry Wiggin and Co., Ltd. The reeling machine is capable of handling mild-steel bars from 1¼ in. up to 5 in. in dia. and high-tensile steel bars up to 4 in. in dia. The bar-shearing machine has been supplied to cut mild-steel bars up to 4 in. square and 3 in. square high-tensile sheets of about 75 tons tensile at an angle of 30°.—M. D. J. B.

Slab Slicer Eliminates Common Shear Troubles. (Steel, 1950, vol. 127, Aug. 21, pp. 100–102). A brief description is given of a new open-sided up-and-down cut slab shear developed by the Sack Machinery Co. Advantages claimed are positive control of the slab, elimination of depressing roller table, quick release of sheared slab portions and unobstructed access to the shear throat.—A. M. F.

Fits for Rolling Bearings. R. Mundt. (Stahl und Eisen, 1950, vol. 70, Aug. 17, pp. 745–755). The ISA (International Standard Association) system of fits is suitable for application to roller bearings and is now internationally accepted. The factors governing the selection of the correct fits for roller bearings are mainly the magnitude and direction of the forces which will arise, but the cross-section and load on the bearings can also affect the fit. The usual practice is fixed fit for the inner ring and sliding fit for the outer ring. A special method of producing the fixed fit for the inner ring is the use of a bearing with a taper hole and a bush to correspond; a new technique is the 'pressure oil method' (developed by SKF) which can be used for both press and shrinkage fits. Correct

fit for the moving ring of a roller bearing is essential if a long life is to be obtained, and bad fits can soon cause serious damage.—R. A. R.

Power Truck Transportation in Steel Plant. C. S. Schroeder. (Iron and Steel Engineer, 1950, vol. 27, Oct., pp. 66–68). The modern tendencies, to suit production, of making larger and longer plates, rods, sections, and coils are briefly discussed in the light of handling equipment. The development of fork-lift trucks is described; initially these were limited to the handling of small loads, but recently heavy equipment has become increasingly popular. The author describes lift trucks capable of handling and stacking bundles of wire and coils up to 60,000 lb. Stress is laid on the importance of providing adequate roads, passages, and manœuvring space in plant layout. A new truck, in the process of development, for the handling of bricks is also described.—M. D. J. B.

The Mechanism of Material Handling. C. Whiteford. (Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 95–99). This article describes the recognition which the Ford Motor Co. management has given to material-handling engineering and operations, the organization and responsibilities set up and assigned, and the procedure followed in analysing a material-handling problem for better methods and installation of modern equipment.—M. D. J. B.

Ore Unloader Built on East Coast. W. B. MacLean. (Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 122–124). This article describes a new 15-ton unloader for handling imported iron ore. The unloader features a combination of welded and riveted construction to achieve maximum functional ability with minimum maintenance in a salt-laden atmosphere. The main dimensions and structural features are given as well as information on the electric motors and general operating characteristics. Special attention has been paid to fatigue stresses and how best to ensure a trouble-free life for all parts of the equipment. The main digging grab has a capacity of 15 tons; a 7·5-ton grab is used in small hatches and for 'cleaning up.'—M. D. J. B.

Developments in the Design of Coal and Ore Bridges. B. A. Rose. (Iron and Steel Engineer, 1950, vol. 27, Oct., pp. 60–64). Stress is laid on the importance of continued trouble-free operation of coal and ore bridges. In order to achieve this the author suggests features which should improve crane performance. These include: (1) The adoption of the simple two-motor hoist with totally enclosed gears; (2) a new design of turntable; (3) simplification of the spring suspension and cradle-type trolley drive; (4) the use of a frame-mounted motor with a totally enclosed axle-hung gear case and rubber-mounted axle suspension scheme; (5) the more simple and reliable friction or spring type trolley buffer used with 'slow down' and final 'stop' limit switches; (6) variable voltage control; and (7) the use of welding which provides a structure which is more readily cleaned and protected from corrosion. M. D. J. B.

How to Evaluate a Crane Proposal. F. M. Blum. (Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 125–132). The object of this paper is to give the man who may not be a crane specialist sufficient information to be able to form his own opinion on the type of crane he should obtain for a particular job. The author suggests that it is incautious to buy cranes on the lowest bid principle. For the purpose of classification, cranes are divided into five groups as follows: (1) Cranes used for stand-by duty such as in powerhouses; (2) light-duty cranes such as in machine shops; (3) moderate-duty cranes such as in light foundry and storage yards; (4) constant heavy-duty service cranes as encountered in production lines and heavy foundries; and (5) very severe duty as for magnet operation, grabs, and stockyards. Operating characteristics and design features of these five types are discussed.—M. D. J. B.

An Improved D.C. Crane Hoist Control. S. Rifkin. (Iron and Steel Engineer, 1950, vol. 27, Oct., pp. 90–96). A new D.C. crane hoist circuit which has the following characteristics is described: A flat speed-torque curve for the first lowering point of the master switch; a starting torque on the first lowering point of the order of 10–35%; a kick-off torque on the second lowering point of 50% in order to permit rapid acceleration of a light load; and the fastest lowering point of the controller to provide stable motor operation up to 140% of the rated motor torque. For hoisting the characteristics are: The first hoist point to provide sufficient stalled-motor torque to hold the rated load without downward drift; the second hoist point to provide sufficient torque to lift the rated load at slow speed; the first and second hoisting points to provide dynamic braking for rapid deceleration of an empty hook; and lastly the number of devices on the control panel to be kept to a minimum for simplicity.—M. D. J. B.

Automatic Couplings. J. Wagner. (Przeglad Techniczny, 1950, June, pp. 298–303). [In Polish]. A short historical survey of automatic coupling for railway wagons, and types at present in use, is made. The safety and economic aspects of this equipment are discussed.—V. G.

Cooling Towers in the Metallurgical Industry. Z. Kazubski. (Hutnik, 1950, vol. 17, May–June, pp. 118–123). [In Polish]. Data necessary for the calculation of the main dimensions of water-cooling towers, their component parts, and types of cooling tower used in the metallurgical industry are described.—V. G.

Electrical Fault Indicator Reduces Down Time. R. W. Cochran. (Iron and Steel Engineer, 1950, vol. 27, Sept., pp. 91–93). A brief review is given of the advantages and scope of fault indicators and safety devices in steelworks. These are especially necessary in fast operating units such as electrolytic tinning lines. Fault indicators attached to blast-furnace skip hoists, and air conditioning units are also considered. Where these have been installed availability of plant has shown a definite increase.—M. D. J. B.

Sliding Contacts for Transfer of Electrical Energy for Industrial Systems. H. Y. Mageoch. (Iron and Steel Engineer, 1950, vol. 27, Nov., pp. 110–116). In this article the systems available for providing third rail or sliding electrical contacts are discussed. A classification of collector systems is given together with information on collectors and collector-shoe material. Different types of insulator are described and their relative merits considered. General comments are given on the selection of the best materials in relation to costs and maintenance. Special systems providing a high degree of safety are also described.—M. D. J. B.

LUBRICANTS AND LUBRICATION

The Nature of Friction. H. B. Locke. (Metal Industry, 1950, vol. 77, Dec. 22, pp. 303–305; Dec. 29, pp. 323–324). The author reviews briefly the present theories of wear and boundary lubrication. The latter phenomenon, which inhibits pressure welding, occurs on all surfaces except those specially cleaned, degassed, and *in vacuo*. Normal 'dirt' is enough to provide boundary lubrication. The mechanism of friction and 'stick-slip' motion is discussed with reference to the mechanical and electrical explanations. The action of bearing metals is also outlined, and reference is made to surface lubricant films and metallic soaps. There are 25 references.—P. M. C.

Investigation of Bearing Materials under Various Degrees of Lubrication in the Low-Speed Range. L. A. Nowell, jun. (Bulletin of the American Society for Testing Materials, 1950, Sept., pp. 47–53). This is the first of a series of reports in which the behaviour of several bearing materials under various conditions of lubrication is studied. A description is given of a modified Amsler wear-testing machine used for the purpose. The apparatus is so designed that the oil film and bearing-alloy temperatures, rate of oil flow through the bearing, journal speed, total load, frictional torque, and continuity of the oil film can be accurately determined. Control experiments have been carried out with 30° and 60° steel-backed Navy Grade 2 tin-base babbit bearings operating on a 2-in. journal, using a U.S. Navy oil.—J. J.

High-Pressure Lubrication in Machine Construction. H. Endriss. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, July 21, pp. 571–576). The need for lubricating reciprocating and rotating machine parts has only recently been fully appreciated. The oilcan has been gradually displaced, first by drip and wick appliances, then by oil rings and grease boxes. Nowadays both closed and open circulation is employed, each having its own field of application. The former, which requiries a much greater quantity of lubricant, is particularly suitable for high-speed shafts and all conditions in which the lubricant also acts as coolant. The latter is more economical in lubricant and is suitable where bearings are at some distance from each other. Oil is used in fully enclosed parts, grease is preferable where dust has access to the bearing. Centralized greasing stations are

recommended for large machinery; these should not only be easily accessible but also made clearly visible for regular maintenance.—J. G. W.

Forging Die Lubrication. W. E. Lang. (Metal Progress. 1950, vol. 58, Sept., pp. 337–339). A thin water emulsion of colloidal graphite is a superior coolant and lubricant for hot-work dies, and the spray nozzles that are attached to the frame of the forging machine or recessed in the dies, can easily be automatically controlled.—E. T. L.

Centralized Lubrication at a Steel Rolling Mill. (Scientific Lubrication, 1950, vol. 2, Oct., pp. 15–18): **Cold Sheet-Mill Installation at Partridge Jones and John Paton Ltd.** (Sheet Metal Industries, 1950, vol. 27, June, pp. 492–494). This article describes in detail the bearing and lubrication systems installed on a battery of six cold-rolling mills. The mills were built by Robertson and Co. and are in two trains of three, each train being driven by a 300-h.p. constant speed motor. All stands are two-high, rolling speed is 36 r.p.m., and the rolls are all 28½ in. in dia. Top and bottom bearings are white-metal lined, and a comprehensive system of lubrication known as 'multipoint Battery' has been installed by Tecalemit, Ltd. The method of operation of the Tecalemit 'grease discharge unit' is described in great detail.—P. M. C.

Phosphate Coatings. M. B. Roosa. (Scientific Lubrication, 1950, vol. 2, Oct., pp. 19–21, 31). The use of Parco Lubrite, a wear-resisting coating of iron and manganese phosphates on bearing surfaces is described. It is claimed that it: (1) Prevents welding of metals under load; (2) increases lubrication efficiency; (3) assures rapid and safe running-in; and (4) chemically smooths the bearing surface during application.—J. W. P.

WELDING AND FLAME-CUTTING

The Weldability of Converter Steel and Its Application in Welded Structures. H. Buchholtz. (Schweissen und Schneiden, 1950, vol. 2, Feb., pp. 23–32, Mar., pp. 51–55). The weldability of converter steel is discussed. Bend test results have shown that the weld strength lies above that of the parent metal. Deep-drawing tests on 1 to 2·2-mm. sheet gave good results. It was found that the notched bar impact test does not give sufficiently accurate information on the weldability of the steel. A critical evaluation of test results is given which shows that converter steel has a limited weldability.—U. E.

Influence of Sulphur and Phosphorus on the Weldability of Carbon Structural Steel by Arc Welding. F. Donis Ortiz. (Instituto de la Soldadura, 1950, Publication No. 11, pp. 5–29). [In Spanish]. The author discusses the characteristics of Spanish welding-quality steels, the types of weld metal; the dilution of the base metal by the weld metal; the forms in which sulphur and phosphorus occur in steel and the causes of their deleterious effect; influence of sulphur on the porosity of the weld metal and on the mechanical properties of the weld; joint effect of high contents of sulphur and phosphorus; practical workshop methods for determining abnormal quantities of sulphur and phosphorus; methods for counteracting the effects of sulphur and phosphorus; action of the heat from the arc on the structure of the transition zone; and the influence of the quality of the electrode coating on the properties of a weld containing excessive sulphur and phosphorus. It can be said that sulphur and phosphorus contents not exceeding 0·06% each and properly coated electrodes guarantee correct welding. If the electrode metal does not contain more than 0·02% P, then up to 0·07–0·075% P may be permitted in the base metal. The quality and capacity of an electrode for welding steels high in sulphur and phosphorus can be determined by the following tests: (*a*) Analysis of the pure weld metal deposited by the electrode, supported by a cracking test; and (*b*) rupture tests on heterogeneous weld samples. Where no facilities exist for analysis or rupture tests, recourse can be had to cold bend tests of welded plates. Hot forgeability tests are also useful. A bibliography of 79 items is given.—R. S.

The Influence of Sulphur and Phosphorus on the Weldability of Constructional Steels. P. Ch. van der Willigen. (Instituto de la Soldadura, 1950, Publication No. 11, pp. 30–40). [In Spanish]. Steels containing more than 0·3% of sulphur should not be used for welding. Phosphorus up to 0·2% is permissible unless the steels are in service at low temperatures. The influence of sulphur on the mechanical properties of the weld metal largely depends on the type of electrode used. A clear distinction must be made between cracks and porosity in the weld metal. For the four main types of electrode, the sulphur range necessary to avoid these defects is 0·04 to 0·20%. The most satisfactory theory is that porosity in the weld is due to the retarding effect of the sulphur on the escape of the hydrogen contained in the solidifying iron. Since the supersaturation by hydrogen immediately below the solidification point will also be greater in the presence of sulphur, the hydrogen pressure will be higher and will tend to cause cracks in the steel. The influence of phosphorus on the mechanical properties of the weld is limited to causing cracks, and these do not appear till the phosphorus content of the base metal is over 0·1%. This, again, depends on the type of electrode used and the service temperature of the part. The author has never found that porosity could be traced to the presence of phosphorus.—R. S.

Weld Metal Properties at Low Temperatures. T. M. Armstrong and W. L. Warner. (Welding Journal, 1950, vol. 29, June, pp. 295s–302s). Experimental data are given on the properties of metal deposited by ferritic nickel–steel electrodes containing up to approximately 5% of nickel, 25/20 stainless steel, Monel, and a nickel–chromium–iron alloy (80% Ni) containing columbium. Results indicate that low-temperature impact properties sufficient to meet requirements of most commercial specifications can be obtained at temperatures down to below — 150° F. with some commercial nickel–steel electrodes with low-hydrogen types of coating. Properties of the weld metal are affected more by change in welding current with some electrodes than with others. Stress-relieving did not improve the properties of all-weld metal in welds ¾ to 1⅛ in. thick.—U. E.

Study of Core Wire for Electrodes. C. B. Voldridi, D. C. Martin, and P. J. Rieppel. (Welding Journal, 1950, vol. 29, June, pp. 265s–284s). The influence of the core wire on the characteristics of low-carbon steel welding electrodes was investigated. Bare wire inspections and tests together with welding tests on wires covered with three types of coating were carried out. The welding tests were made using direct-current welding generators. Sulphur contents of more than 0·04% caused the electrodes to have deficient operating characteristics and severe weld-pitting tendencies. Best results were obtained when the sulphur did not exceed 0·03%. Tables are included giving chemical composition and core area ratios of wire from top, middle, and bottom billets of best ingots.—U. E.

Determining Total Water Content in Electrode Coverings. C. T. Gayley and W. H. Wooding. (Welding Journal, 1950, vol. 29, Aug., pp. 629–635). A new and improved method is described for determining the total water content (hygroscopic and combined) of mineral-type coverings of welding electrodes. The method utilizes an analytical absorption train in which the sweeping media pass successively through a purifying and drying train, a combustion tube mounted in a high-temperature furnace, and finally through the absorption train. Using oxygen as a sweeping medium, various furnace temperatures were investigated to establish a satisfactory temperature for determining the total water content of several covering constituents and coverings of shielded-arc welding electrodes. The results confirm the reproducibility of the method described.—U. E.

Modern Electrode Production. (Welding, 1950, vol. 18, June, pp. 248–254). The manufacture of electrodes for electric arc welding as developed by the Quasi-Arc Co., Ltd., is described. Over 150 different types and sizes of electrode are produced and the Company is responsible for a comprehensive range of specially designed welding plant and accessories.—U. E.

Alloying Elements in Chromium–Nickel Stainless Steels. H. Thielsch. (Welding Journal, 1950, vol. 29, Aug., pp. 361s–404s). This is a review of information and data available on stainless steels. Emphasis is placed on the effects of residual and alloying elements on the physical and welding metallurgy of the major grades of stainless steel. Available information in wrought and cast grades is also presented. It is shown that the following factors determine the suitability of chromium–nickel electrodes and the amount of carbon which may safely be present: (1) Corrosive environment of

welded joint; (2) mechanical requirements of the weld; (3) possible applications at elevated temperatures to which welds may be subjected; (4) percentage of chromium and nickel present in the steel and in the electrode; (5) presence of minor alloying elements and/or of carbide stabilizing elements; (6) welding processes such as electric arc, atomic hydrogen; and (7) possibility of heat-treatments before and after welding.—U. E.

Present Principles and Development of Electric Arc Welding. J. Martinez Paris. (Boletin de Informacion del Instituto de la Soldadura, 1950, No. 6, pp. 7–21). [In Spanish]. After describing the different types of arc used for welding, the author discusses the development of electric welding in Germany. A series of design principles for webbed beams is given. Important welding jobs in Belgium, England, and Italy are mentioned. American developments are reviewed from the economic point of view. The welding of special sections, the use of 'positioners' and the development of high penetration electrodes are briefly described. The first Spanish electrodes were made in 1932. Some notable Spanish welded constructions are mentioned.—R. S.

Automatic Inert Gas-Shielded Arc-Welding Operations. H. O. Jones. (Welding Journal, 1950, vol. 29, Aug., pp. 655–656). Automatic inert-gas-shielded arc-welding is described. The fabrication of long or short butt welds can be accomplished with suitable jigs and simple mechanical 'Heliweld' equipment. A recent development is the mechanical wire feeder, which automatically feeds the wire at speeds ranging from 15–260 in./min. The operation therefore can control the amount of wire deposited, thus governing the size and contour of the deposited bead. A permanent magnet incorporated in the gas nozzle eliminates to a great extent arc interference.—U. E.

Mash Resistance Welding Produces Flat Seams in Steel. O. Broner. (Materials and Methods, 1950, vol. 32, Oct., pp. 77–78). Mash welding is a new application of resistance welding technique. It makes use of standard seam welding equipment to produce end to end joints in thin mild-steel sheet. The amount of overlap is limited to 1½ times the sheet thickness, and the welding pressure is approximately twice that used for conventional seam welding. The stock requires no special preparation, and, after welding, the joint is only 10–15% thicker than the base sheet and requires no finishing. The limitations of the process, from the point of view of materials and applications, are briefly discussed.

P. M. C.

The Resistance Welding of Mild Steel Sheet. W. S. Simmie. (Welding Journal, 1950, vol. 29, Aug., pp. 651–654). British and American methods for the resistance welding of mild-steel sheet in the automotive industry are compared. Production quantities are much larger in America and multi-headed welding machines are being used in considerable numbers. The automobile industry is the largest user of resistance welding equipment in Britain.

Influence of Microstructure on the Behaviour of Low-Carbon Steel in Resistance Welding. W. Eilender and R. Mintrop. (Stahl und Eisen, 1950, vol. 70, Aug. 3, pp. 702–707). The changes resulting from welding of cementitic and pearlitic low-carbon steels have been used to study the effect of structure on weldability. The cementitic steel was difficult to weld, the pearlitic easy. This difference in behaviour can be accounted for by the sluggishness of the dissolution of cementite in austenite and the lack of uniformity of carbon in the weld. If good weldability at high speeds is required, the steel should be heat-treated so as to possess a uniform carbide distribution and uniform grain size.—J. P.

Behaviour of Unalloyed Low-Carbon Strip Steel in Resistance Welding and Its Testing. W. Eilender and K. Holzhausen. (Stahl und Eisen, 1950, vol. 70, Aug. 3, pp. 698–702). A new testing procedure has been developed in which a strip of steel is heated to melting by an electric current. The time and power required to effect this melting are measured by cathode-ray oscillographs and the temperature of the specimen is recorded photographically. When the results are compared with practice it is found that the better the weldability of the steel, the lower is the specific power requirement (in watt-sec./sq. mm. of cross section) and concomitantly, the greater is the heat evolved in an exothermic reaction taking place between 1148° and 1338° C. It is shown, contrary to usual assumptions, that low carbon, silicon, and manganese are not essential for good weldability, the structure of the steel, as affected by heat-treatment, is all important. The heat evolved in the above-mentioned reaction is greater with a pearlitic than with a granular cementitic structure. Since the microstructures of commercial steels vary between these two extremes, the reason for the 'temperamental' welding behaviour of otherwise similar materials is clear.—J. P.

The Progress in Boiler and Pressure Vessel Design and Practice by the Use of Welding. N. A. Falconer. (Welding Engineer Symposium, Sydney: Australasian Ergineer, 1950, Oct. 7, pp. 53–57). The author outlines the manner in which welding has become accepted as a reliable fabricating method during the past generation. Welded designs require less material, and enable thicker vessels with higher working pressures to be made, than do riveted designs. Welding equipment is briefly described, and radiographic, gamma ray, and supersonic methods of inspection and equipment are discussed.—P. M. C.

Oxy-Acetylene Welding to the Right. C. G. Keel. (Revue de la Soudure, 1950, vol. 6, No. 1, pp. 1–19). A method of oxy-acetylene welding to the right is described in which particular attention is given to the filler metal. In this the weld, while still hot, is heat-treated with the burner. The method has been thoroughly tested by the Société Suisse de l'Acétylène at the Federal Materials Testing Laboratory in Zürich between 1946 and 1948. The heat-treatment carried out with the burner consists in heating the joint after welding to a temperature above 900–950° C., in the manner described. The tests have enabled the three best types of filler metal to be selected and their hardness, percentage elongation, tensile, flexural, torsional, and bending strengths to be measured. These it is shown are more than adequate for welding purposes. A good resistance to fatigue was obtained as well as high resistance values. The influence of hydrogen on the resistance of welds is examined and practical examples of the application of the method are given. The tests have led to the preparation of a specification for filler metal rods and have enabled better-grade rods with a greater resilience to impact stresses to be produced.—M. D. J. B.

The Inspectors' Approach to Arc Welding. C. W. Ephithite. (Welding, 1950, vol. 18, May., pp. 218–222). Various duties of any inspector or supervisor responsible for maintaining satisfactory standards of welded work are discussed. The weldability of material, preparation, assembly of components, skill of the operator, welding procedure, plant, and electrodes have to be considered. A practical and theoretical knowledge of welding and a planned programme of inspection will ensure best results.—U. E.

Energy Distribution in Electric Welding. C. E. Jackson, and A. E. Shrubsall. (Welding Journal, 1950, vol. 29, May, pp. 231s–241s). The energy distribution in welding with both coated electrodes and the submerged melt process is discussed. New data are presented showing the utilization of energy in forming the weld nugget which constitutes the weld joint. The losses which are encountered for various welding techniques are considered. The energy utilized in melting the electrode for both coated electrodes and submerged melt welding for all current levels is approximately 15% of the total energy input. The rate of melting the electrode for both coated electrodes and submerged melt process increases with current. Auxiliary energy, amounting to from 50–80% of the total energy input is utilized in heating the plate, radiation, fusing the melt or coating, convection, and spatter. The energy utilized in forming the weld nugget which constitutes the weld joint for both coated electrodes and Unionmelt processes ranges from approximately 20 to over 50% of the total energy input, the energy utilization increasing with current and speed of travel.—U. E.

Welding of Corrosion and Heat Resisting Steels. J. A. McWilliam. (Welding, 1950, vol. 18, Mar., pp. 94–99, Apr., pp. 150–156). The weldability of chromium–nickel corrosion-resisting and heat-resisting steels is discussed. In welding these steels a coefficient of expansion of about 50% greater than that of mild steel has to be allowed for. The thermal conductivity is less and more care must be taken to avoid distortion. Different welding techniques are discussed.—U. E.

The Manufacture of Fusion-Welded Boiler Drums at Renfrew. (Engineering and Boiler House Review, 1950, vol. 65, Apr., pp. 112–118). **Fusion Welded Pressure Vessels.** (Welding, 1950, vol. 18, Apr., pp. 140–149). The fusion

welding of pressure vessels as carried out by Babcock and Wilcox, Ltd., has been described. Boiler drums and special vessels withstanding a pressure of about 1124–1320 lb./sq. in. are successfully welded in multilayer runs. All welds are investigated by X-ray using a 2,000,000-V. Newton-Victor apparatus to ensure a faultless joint.—U. E.

Automatic Electric Hard Facing. T. G. Brashear, jun. (Welding Journal, 1950, vol. 29, May, pp. 391–398). The automatic submerged melt welding process is described and several examples of its application for repairing worn parts of machinery are illustrated and discussed.—R. A. R.

Renovation of Worn Rolling-Mill Rolls by Welding Iu. A. Kalachev. (Avtogennoe Delo, 1948, No. 1, pp. 29–30). [In Russian]. An account is given of the use of welding for repairing worn rolls to give a surface of Brinell hardness greater than 150, the necessary carbon content of at least 0·45% being secured by mixing 20% of graphite into the chalk coating of the electrode or by coating the electrode with stalinite. It was found that stalinite could also be successfully used for building up wobblers which were worn down as much as 50%, the powdered alloy being heaped to a depth of 4–6 mm. on the surface and fused on with the arc directed at the edge of the heap at 45°.—S. K.

Shrinkage and the Effects of Shrinkage Due to Electric Arc Welding. H. E. Jaeger. (Revue de la Soudure, 1950, vol. 6, No. 2, pp. 83–95). This paper examines in detail the causes and effects of shrinkage in arc-welded work. The effects of alternate heating and cooling are discussed and it is shown how a piece of steel submitted to repeated heating will increase in directions in the heated zone, with a corresponding reduction in size in the adjoining parts. Reference is made to the work of Bibber, de Garmo, Weck, Stocks, and Thurston. The cumulative effects of welding large structures are considered and the behaviour of welded ship plates discussed. Correct sequences for welding ship plates are given as well as methods of stress-relieving. Longitudinal and transverse residual stresses and the means of overcoming these are described. Based on information obtained from a large number of tests, the author concludes that the influence of the type of electrode and variations of welding currents have only little effect on shrinkage; the speed of welding plays an important part in shrinkage, the faster the welding the smaller the shrinkage; the rate of cooling has much effect, the slow cooling of welds reducing the amount of shrinkage. Lastly, the author stresses the fact that by far the most important factor affecting shrinkage is the number of runs in a weld, these should be kept as low as possible. It is for this reason that the Union-Melt process has proved so successful.—M. D. J. B.

Modern Resistance Welding with Precision Equipment. R. Bouillon. (Revue de la Soudure, 1950, vol. 6, No. 3, pp. 144–159). Detailed descriptions are given of modern resistance-welding equipment and stress is laid on the fact that this equipment now belongs to the class of high-precision machine tools. A review is given of the progress made in this field in the last ten years, notably in the U.S.A. The development of both the mechanical and electrical components of welding equipment is examined in detail as well as a number of special resistance-welding machines. These give an indication of the extremely wide field of application of this type of welding. The advantages claimed in transforming three-phased alternating current are discussed in detail.

M. D. J. B.

Electronic Control of Modern Resistance Welding Apparatus. F. Viart. (Revue de la Soudure, 1950, vol. 6, No. 3, pp. 160–168). This paper examines the problem of dealing with welding currents of the order of several hundred ampères applied for time intervals ranging from 1 sec. down to 0·1 sec. Transitory switching phenomena, the choice of cut-out time, synchronous control, and electronic contactors are discussed as well as thermal control. Electronic control apparatus for 50-cycle welding as well as low-frequency welding at 10, 7½, and 5⅝ cycles/sec. is described.—M. D. J. B.

Spot Welding—A Comparison of British and American Practices. A. J. Hipperson. (Welding, 1950, vol. 18, Mar., pp. 112–117). American and British codes of practice for spot welding mild steel are discussed. American and British recommendations are in reasonably close agreement. America tends to use higher currents and pressures and shorter welding times, which impair the weld strength. The American settings are shown to give about double the scatter in test results that the British practice gives. With the American settings applied to 14 S.W.G. sheet a 6% increase in productivity can be obtained.—U. E.

Grain Size and Shear Strength in Spot Welding. F. Bischof. (Die Technik, 1950, vol. 5, Mar., pp. 129–131). Whilst it was expected that the shear strength would depend on the secondary grain size in spot welding on account of the increase of thermal conductivity with grain size, no experimental evidence of this is available in the literature. In the experiments performed by the author unkilled basic-Bessemer 0·08% C bright steel sheets 1 mm. thick were used, the grain size being varied by annealing at 900°, 1000°, 1100°, and 1200° C. The welding procedure was varied by varying the contact pressure, welding time, and the current. Each seam consisted of at least five spots. The specimens were pulled in a tensile testing machine. It was found that the shear strength decreased with increasing grain size and this dependence was unaffected by the change in welding procedure.

J. G. W.

Effect of Cold Work on Shear Strength of Spot-Welded Seams. F. Bischof. (Die Technik, 1950, vol. 5, Mar., pp. 132–133). Experiments in which the amount of cold work was varied confirmed that the shear strength of spot-welded seams increases with the amount of cold work received by the parent metal before welding. The experiments were performed on 0·05% C unkilled basic-Bessemer steel sheet 1 mm. thick, normalized at 900° C. and drawn in accordance with the wedge test described by H. Kayseler and W. Püngel in which the elongation by drawing varied from 0 to 60%. Two contact pressures of 90 and 190 kg. were used, the welding time was 1 sec., and the copper electrodes had a contact surface 5 mm. in dia. The increase in shear strength for the 60% cold work was of the order of 60%.—J. G. W.

Index of Welding Wire and Standardization of Welding Electrodes. H. Fröber. (Die Technik, 1950, vol. 5, May, pp. 267–272). Proposals are made for the standardization of welding wire and electrodes, based on a critical survey of the earlier German, Russian, British, and U.S.A. standards. A classification of wires according to composition with a subdivision according to the type of coating and application is outlined and symbols denoting each type are suggested.

J. G. W.

Direct Explosion of Welded Joints. G. S. Mikhalapov. (Welding Journal, 1950, vol. 29, Mar., pp. 109s–122s). The direct-explosion test (to determine the triaxial sensitivity of steel plates and weldments) consists of detonating an explosive charge in direct contact with the specimen supported along its four edges. Low-carbon, low or medium-manganese steels and low and medium-carbon, low-alloy steels welded with four different types of electrodes were tested. Good correlation appears to exist between the load-carrying capacity of welded joints as determined by the direct-explosion test and by the static loading to destruction of a fabricated structure containing a steep stress gradient. Wide differences are found to exist in the energy necessary to fracture and in the extent of plate deformation before fracture of ferritic steel plate particularly at subzero temperatures depending on the density and heat-treatment. The strength of welded joints can be greatly improved by the use of proper alloy electrodes.—U. E.

Notch Sensitivity of Welded Steel Plate. L. J. McGeady and R. D. Stout. (Welding Journal, 1950, vol. 29, May, pp. 243s–251s). Criteria are given for determining transition temperature and for rating notch toughness of structural steels. Fifteen heats of steel representing two thicknesses of plate, six structural grades ⅝ to 1 in. thick and a variety of mill practices have been rated in notch toughess by the longitudinal-bead notch bend test. The behaviour of as-rolled plate gives no indication of the characteristics of welded plate. No correlation was found between manganese/carbon ratio and transition temperature in either as-rolled or welded plate. A correlation was developed between carbon content plus 20 times the phosphorus content and transition temperature of welded plate.—U. E.

Stress Distribution around Spot Welds. A. O. Bergholm, P. W. Swartz, and G. S. Hoell. (Welding Journal, 1950, vol. 29, May, pp. 217s–223s). An investigation was carried out on the stress distribution around spot welds in two flat

bars of low-carbon steel joined by two and three spot welds. Strain gauge readings taken on the two spot joints revealed that the maximum tensile stresses occur along the lines of the applied force in the region between the spot welds. It is concluded that single laps of spot-welded joints are inherently weak due to the unavoidable bending of the plates. Double laps (one plate sandwiched between two plates) will reduce considerably the high stress concentrations set up at the weld spot. Relief of stress concentration can be obtained by proper removal of material (such as drilled holes) to redistribute the stresses near the weld. The joining of two plates by one row of resistance spot welds is inherently unsound. U. E.

Strain-Aging of Arc Welds in Mild Steel. A. E. Flanigan, M. Kaufman, and E. M. Emery. (Welding Journal, 1950, vol. 29, Mar., pp. 146s–160s). Strain-ageing characteristics of a number of welds made on mild-steel plates were investigated using the bead-on-plate notched bend test at −40° F. to determine the ductility. Prestraining, duration of ageing both before and after prestraining, ageing temperature, and temperature at which fracture occurred were investigated. Susceptibility to strain-ageing appears to be generally characteristic of arc welds on mild steel. Maximum strain-age embrittlement was observed at room temperaturre within a week after prestraining. Less than one month was sufficient to restore ductility. Strain-ageing effect is believed to reside in the weld metal itself rather than in the heat-affected zone or parent plate.—U. E.

The High Frequency Notch Bend Test. Bela Ronay. (Welding Journal, 1950, vol. 29, Mar., pp. 122s–125s). The paper presents an economical method for determining arc welding procedure for ferritic steels. A series of wrought and cast Cr–Mo steels intended for high-pressure, high-temperature application was investigated using the high-frequency notch bend test. The wrought steels were not notch sensitive in the as-received condition and this property was fully restored by preheating and post-heating. The cast materials tested showed a tendency towards notch sensitivity in the as-received condition for those with a carbon content exceeding 0·25%. Maximum sensitivity was observed in the steel containing 0·28% C.—U. E.

Weld Embrittlement in Chromium Stainless Steels. H. Thielsch. (Welding Journal, 1950, vol. 29, Mar., pp. 126s–132s). A new type of embrittlement occurring in low-carbon high-chromium steels has been investigated using high-temperature quench tests, induction heating techniques, and weld tests. Severe grain growth is found to accompany embrittlement which occurs in the ferritic grades, and hardness values alone do not give a true indication of the other mechanical properties. Annealing between 1350° F. and 1450° F. will remove most of the effects of the high-temperature embrittlement but a post anneal is by far the best and should be employed wherever a restoration of the ductile properties of the steel is of major importance.—U. E.

Seam Welding Monel Metal to Steel. E. F. Nippes, A. R. Pfluger, and G. M. Slaughter. (Welding Journal, 1950, vol. 29, Mar., pp. 134s–140s). Resistance seam welding of Monel to low-carbon steel in 0·062-in. gauge was carried out. A heterogeneous weld nugget resulted by fusing the Monel and steel which led to porosity and cracking in the weld zone. A 'braze' type weld was made in which fusion occurred only in the Monel. The weld strength was better than that obtained with steel to steel. A minimum of porosity and much better surface appearance were obtained using an electrode having a 6-in. radius dome face.—U. E.

Preliminary Results of Welding-Peening Investigation. J L. Wilson. (Welding Journal, 1950, vol. 29, Mar., pp. 97s–108s). Optimum temperature, size of hammer, size and shape of tool, and relative 'riding' of the hammer are discussed. It is found that the 'riding load' has a marked effect upon the hammer performance characteristics. In certain conditions 'riding load' has an effect comparable with that resulting from varying air pressure.—U. E.

Bronze Welding—Procedures for Different Metals and Applications. T. J. Palmer. (Welding, 1950, vol. 18, Apr., pp. 159–164). Bronze welding is applied to high-melting-point ferrous and non-ferrous metals. Strong, ductile joints can be made in cast iron and steel, malleable and wrought iron, copper and nickel, and most of their alloys. In bronze welding, the parent metal is not melted and the added metal is not of the same type so that the bead is a superficial one. A minimum of heat is induced into the work resulting in less distortion stresses and no change in microstructure of the parent metal. The limitations of this process are discussed. U. E.

Brazing and Welding Coated Materials. E. V. Beatson. (Welding, 1950, vol. 18, June, pp. 232–242). Brazing and welding of various types of coated material such as nickel, copper, tin, and zinc-coated steel are described. These coated metals cannot be welded by a flame or the electric arc. Good weldability of thin-coated materials can be obtained with resistance welding, *i.e.*, spot welding, if the quality of the coating as regards adhesion, porosity, and consistent thickness is of the highest standard.—U. E.

A New Procedure for Flame Cutting—Oxy-Kinetic Flame Cutting. A. E. Leduc. (Revue de la Soudure, 1950, vol. 6, No. 1, pp. 31–41). This paper describes a new method of flame-cutting high-alloy steels such as 18/8 stainless steel. The difficulties encountered in using the ordinary flame-cutting methods are considered and proposals to overcome these difficulties are made. So far, all methods have attempted to modify the viscosity of the slag to assist its expulsion by the oxygen. The new method consists of loading the cutting oxygen with solid particles and using the combined action of the oxygen and the kinetic energy of the particles to clean out the cut. The fundamental theory of the new method is developed; the types of sand used as projectiles, the apparatus, and the cutting technique are described. Details are given of the results obtained in cutting both stainless steels and cast iron.—M. D. J. B.

Powder-Cutting and Scarfing Processes. R. S. Babcock. (American Institute of Mining and Metallurgical Engineers: Blast Furnace and Steel Plant, 1950, vol. 38, June, pp. 674–680). The powder process is explained. A pneumatic and a vibratory design of powder dispenser and a 44-in. long hand-operated powder scarfing blowpipe are described. Details are given of the powder equipment. Two types of apparatus for converting standard hand and machine-operated cutting blowpipes to power-cutting units are described. Details are also given of a machine-type oxygen-cutting blowpipe with single-tube attachment. The application of the powder process in the foundry, non-ferrous applications, the heavy cutting of scrap, and the quick-starting application for cutting carbon steels are discussed. The article ends with a section on conditioning by powder scarfing.—J. P. S.

Oxygen Cutting Processes in Steel Foundries. R. S. Babcock. (American Foundrymen's Society, May, 1950, Preprint No. 50-39). The latest developments in equipment and operating techniques for these processes are described and illustrated, and include hand and mechanized systems and a section on powder cutting which has facilitated the conditioning of stainless steel castings.—E. J. D. S.

New Developments in Oxyacetylene Cutting Machines. W. Begerow, and A. H. Yoch. (Welding Journal, 1950, vol. 29, May, pp. 382–387). Flame-cutting machines and their uses are described and illustrated.—U. E.

Powder Cutting of Ferrous and Non-Ferrous Metals. (Engineering, 1950, vol. 170, July 21, p. 57). A method of cutting is described in which a stream of finely divided combustible powder is fed to the cutting nozzle and burnt in the cutting-oxygen jet. This recent development shows promise of considerably widening the field of application of oxygen cutting. The process has been developed by the British Oxygen Company, Ltd. Details of the process are given as well as of the field of application, which includes the cutting of stainless steels, high-alloy steels, and some non-ferrous metals. The chemical reactions, operating temperatures, and quantities consumed are given.—M. D. J. B.

"OXYARC" Oxygen-Arc Cutting. H. Schmidt-Bach. (Schweissen und Schneiden, 1950, vol. 2, May, pp. 93–96). The oxygen-arc cutting process is described. The electrode consists of a steel tube through which oxygen is passed. Alternating or direct current is used for the arc. Mild-steel plate 5 to 80 mm. thick and stainless steel 3 to 20 mm. thick are successfully cut by this method. Holes are cut in 200-mm. thick mild-steel plate in about 18 sec. The economic aspects are discussed.—U. E.

Uses of Oxy-Acetylene Processes in the Steel Fabricating Industry. C. I. Orr. (Steel Processing, 1950, vol. 36, Nov.,

pp. 577–579, 586). The author outlines briefly the uses of the oxy-acetylene flame in the plants of the Consolidated Western Steel Corp. (U.S. Steel Corp.). These are flame-cutting; flame-gauging back sides of welded seams; preparation of edges for butt welding; weld preheating; and straightening of warped beams and plates.—P. M. C.

Gas and Smoke when Welding Ferrous Materials. W. Hummitzsch. (Schweisstechnik, 1950, vol. 4, Nov., pp. 121–130). The liberation of gas and the fumes during the welding operation and their effect on the health of the operator are discussed. Protective measures are given.—U. E.

MACHINING AND MACHINABILITY

On the Mechanism of Electro Erosion of Metals. S. L. Mandel'shtam and S. M. Raiskii. (Izvestia Akademii Nauk S.S.S.R., 1949, vol. 13, No. 5, pp. 549–565). In the electric spark method of machining developed in the U.S.S.R. the electrode metal vaporizes in the form of luminescent jets or 'flares' which are ejected at a velocity up to several thousand metres/second. Factors affecting the destruction of the work and of the opposing electrode by the flare were studied in the present investigation. The disintegration caused by a pointed conical electrode is considerably greater than that occurring with a blunt electrode. In tests with iron, aluminium, magnesium, and copper counter electrodes the greatest destruction was caused by copper. With a sharp copper cone and small spark gaps it is easy to cause severe damage to steel. When a copper wire cathode was encased in an insulating capillary with the end of the latter projecting 3 mm. beyond the end of the former, this confinement of the flare increased the destruction of the steel anode. If the electrodes are immersed in a liquid the liquid acts in a manner similar to the capillary.—R. A. R.

Electric Arc Cutting of Hard Metal and Steel. T. P. Rekshinskaya. (Schweisstechnik, 1950, vol. 4, Sept., pp. 101–103). This is a German account of the Russian method of 'arc machining' for hardened steel and sintered carbides (*see* Journ. I. and S.I., 1947, vol. 157, Dec., p. 641).

Machining of Stainless Steel. E. v. Hambach. (Metal Progress, 1950, vol. 57, June, pp. 781–791). This is a consideration of the difference in machine shop operations on plain carbon and on stainless steels. Details are given of optimum speed in turning, drilling, tapping, threading, milling, broaching, and reaming. Practical details are also given of machining stainless steel by filing, sawing, and stoning, and lubrication is dealt with.—E. T. L.

Cylindrically Shaped Hard-Metal Cutting Tools. (Technická Práce, 1950, June, p. 91). [In Czech]. Machining experiments were carried out in the Zbrojovka Works, Vsetin (Czechoslovakia) with cylindrically shaped cutting tools placed horizontally. The cutting edges had a negative angle and were fixed so as to have the highest point 0·2 to 0·5 mm. above the level of the spindle axis.—E. G.

Production of Tensile Test Specimens. H. Jennings. (Engineer, 1950, vol. 190, Sept. 8, pp. 248–249). The author describes the manufacture of tensile test specimens on a production basis developed to meet the needs of the present large number of students at the Technical College, Bradford. Normally specimens are turned between centres and possibly ground on the gauge length. In the new method described, the turning of the gauge length and transition curves is replaced by a single milling operation. Means of improving the roundness are also described and the final grinding operation is required only to correct ovality. Using these methods, the rate of production, including handling times, is increased to four specimens/hr.—M. D. J. B.

The Action of Cutting Fluids in Machinery. M. E. Merchant. (Iron and Steel Engineer, 1950, vol. 27, Nov., pp. 101–107). The functions of cutting fluids are discussed under their two main uses, namely, cooling and lubricating. An apparatus for measuring the heat transfer properties of cutting fluids is described. The author shows that oil is detrimental to good heat transfer and therefore that oil content in water-based cutting fluids must be kept as low as possible. The lubricating action of a cutting fluid in reducing friction depends on its chemical properties in forming proper reaction products at the chip-tool interface. Deformation in the metal and heat generated are examined in relation to the shear angle of the tool. It is concluded that at high cutting speeds good cooling ability is of primary importance, while at low cutting speeds good friction-reducing ability is required.—M. D. J. B.

Methods of Measurement and Definition of Surfaces. H. Becker. (Microtecnic, 1950, vol. 4, July–Aug., pp. 180–184). The methods of investigation of surface roughness, surface inspection, and measurement are discussed. Reference is made to straight-edge blade and low power magnification techniques where determination of numerical measurement is not possible. Where surface comparison is required for manufacturing processes, details are given of the surface finish comparator made by Busch and the binocular comparator by Leitz. Direct numerical surface values can be obtained by instruments employing light cross-section methods and micro-interferometry.—H. D. W.

Central Engineering Workshops of the Appleby-Frodingham Steel Company Branch of the United Steel Companies Ltd. G. C. Oram. (Iron and Coal Trades Review, 1950, vol. 161, Aug. 18, pp. 337–343; Aug. 25, pp. 387–393). A detailed and illustrated description is given of the new central engineering workshops of the Appleby-Frodingham Steel Co. After a brief description of the works as a whole, the author describes the construction, general layout and control of the workshops, the organization of the stores, and the facilities for mechanical handling. The training schemes and educational facilities are also briefly reviewed. Before this establishment existed, repairs were undertaken by seven main repair shops, and the author indicates the advantages of centralizing the workshops.
G. F.

CLEANING AND PICKLING

Acid Salvaging Process Cuts Pickling Costs. F. J. Bartholomew. (Steel, 1950, vol. 127, July 31, pp. 68–72). This process involves the concentrating of free acid in the waste liquor to the point where the iron sulphate drops out in filterable form leaving the acid free from sulphate. Concentration is carried out by the direct application of high-temperature combustion gases beneath the surface of the waste liquor.
A. M. F.

Metal Cleaning. M. Reeves. (Metal Industry, 1950, vol. 77, July 28, pp. 54–55). The author stresses the importance of efficient cleaning and surface treatment before the application of modern industrial finishes, (varnishes, cellulose, synthetic lacquers, etc.). He refers briefly to the following methods: Chemical cleaning with phosphoric-acid-base solvents, liquid and vapour degreasing with trichlorethylene and similar solvents, spray pickling, and automatic jet washing.—P. M. C.

Elements of Metal Cleaning—for the Fabricator. A. Bregman. (Metal Progress, 1950, vol. 57, Jan., pp. 75–78). The author discusses the selection of a proper cleaner, types of dirt, and methods of cleaning. The latter include soaking, spraying, electrolytic cleaning, emulsion cleaning, solvent degreasing, and acid cleaning.—E. T. L.

Tin Plate Cleaning and Annealing Cycle May Be Cut to less than Two Days. A. E. Kadell. (Steel 1950, vol. 127, July 24, p. 72). The author describes shortly a new installation planned for continuous cleaning and annealing of tinplate. This includes a cleaning unit, a heating furnace, and a controlled cooling unit.—A. M. F.

Metal Cleaning Problems and Tests for Cleaners. A. Bregman. (Metal Progress, 1950, vol. 57, Mar., pp. 339, 340, 394–406) This is a survey of some methods of cleaning, and of ways of testing their effectiveness. Chemical mixtures for various non-ferrous metals are given, in particular for aluminium. Tests mentioned are the copper sulphate dip method, *p*H and titration value measurement, colloidal property determination, water softening, and conductivity. The article also dealt with soil removal from a metal, and the use of radioactive tracers.—E. T. L.

Tumbling for Low-Cost Finishing. A. Bregman. (Metal Progress, 1950, vol. 57, May, pp. 625–628, 680–694). Surface finish may be given to small metal components by rotating them in a drum with or without a liquid suspension or solution. The theory and apparatus for the process are described, and also the abrasive-carrying media, and abrasives. Dry and wet tumbling are discussed, along with details of the operating technique. It is concluded that although there are limitations to its use, there is scope for a much wider application of the process.—E. T. L.

Health Hazards in Metal Degreasing. P. W. McDaniel. (Metal Progress, 1950, vol. 58, July, pp. 77–78, 102–111). The author considers the dangers of alkaline cleaning, acid cleaning, and solvent cleaning, and the measures that can be taken to safeguard workers. The solvents considered are petroleum solvents and chlorinated hydrocarbons.—E. T. L.

PROTECTIVE COATINGS

Complex Compounds in Industrial Electroplating. S. Senderoff. (Metal Finishing, 1950, vol. 48, July, pp. 59–64; Sept., pp. 71–78). The term complex compound in connection with plating solutions is defined and the factors which influence stability and dissociation are discussed. Complexes have the following major functions: (1) To act as sources of metal, as in cyanides and stannates; (2) to provide addition agents to improve anode corrosion and the physical properties of the deposit; (3) to reduce sensitivity to impurities or to remove them from solution; and (4) to control the deposition potential of the metal—of particular importance in alloy deposition. These functions are discussed at length in connection with copper, nickel, chromium, zinc, cadmium, tin, lead, indium, silver, gold, platinum, rhodium, brass, speculum, and terne plating baths. The properties of these baths, effects of modifications, and spheres of application are dealt with fully. The precise mode of action of most complexes is not fully understood. Radio-active isotope studies of dissociation rates of complexes when correlated with information on polarization and overvoltage might greatly improve our understanding of electrodeposition from complex ion solutions. Studies of the electrochemical properties of complex compounds of those metals which have not yet been deposited in a pure state from aqueous solutions, such as molybdenum, tungsten, titanium, etc., might well yield clues to the direction required for this long-sought advance in electroplating.—J. P.

The Application of Electronics to the Art of Inspection in Materials and Metrology in Industry. J. R. Cornelius. (Engineering Inspection, 1950, vol. 14, Autumn Issue, pp. 100–112). The author gives a very elementary description of the application of the electronic comparator to such problems as dimensional checking, materials checking, and the testing of protective coatings.—P. M. C.

Intrinsic Porosity. (Electroplating, 1950, vol. 3, Sept., pp. 487–490; Oct., pp. 529–531). Intrinsic porosity is an extremely fine form of porosity which must not be confused with other and coarser types of discontinuity. Such fine pores are damaging to an electrodeposit, not so much because they provide channels from the basis metal to the atmosphere but because they are invariably filled with chemicals from the plating solution which accelerate corrosion in moist environments. Such pores are inevitable in thin deposits. In all good plating solutions there is a tendency for the pores to close as the deposit thickens, but this does not happen fast enough with the solutions in use at present. In consequence, in endeavouring to produce a non-porous deposit an uneconomical thickness of plate is built up and yet the defect is not entirely eliminated. The best hope of producing a pore-free deposit which is not thicker than those ordinarily applied today lies in finding a way of making a deposit grow sideways more rapidly. There is some evidence that this rate depends on solution composition and plating conditions. If the intrinsic porosity cannot be prevented, it can be minimized by making the thickness as great as can be tolerated and by ensuring that the surface of the basis metal is as free as possible from stress. This means avoiding hard polishing, rolling, drawing, or similar mechanical operations or, where these cannot be avoided, using a suitable etch to remove the stressed layers. Suitable 'equi-potential' etches have been developed. Other possible palliatives are mentioned.—J. P.

Stripping Electrodeposits. G. T. Colegate. (Product Finishing, 1950, vol. 3, Mar., pp. 32–44, 47). Electrodeposited metallic coatings may require to be removed when they are defective or have served as 'stop-offs' in such processes as nitriding or carburizing. Various methods, electrolytic and immersion, are described for stripping deposits of copper, brass, bronze, nickel, chromium, cadmium, zinc, lead, silver, gold, tin, iron, and rhodium from ferrous and non-ferrous articles. The considerations affecting choice of method are discussed.—J. P.

Laboratory Tests of Protective Coatings *versus* Service Results. W. T. Moran and G. E. Burnett. (Bulletin of the American Society for Testing Materials, 1950, Apr., pp. 73–77). A description is given of the degree of agreement obtained between laboratory and service tests on protective coatings. It is shown that whereas laboratory tests give useful indications of the performances to be expected from materials in service, they are by no means infallible, since phenomena may occur in engineering applications which were not anticipated in these laboratory tests, and which may completely reverse the decision reached on the grounds of the latter.—J. J.

Some Notes on the Electroplating of Stainless Steels. E. E. Halls. (Sheet Metal Industries, 1950, vol. 27, Aug., pp. 747–748). The necessity of electroplate treatments for stainless steel may arise, (*a*) to permit soft soldering using normal solders and fluxes or, (*b*) to provide a surface with a low potential difference from other metals in contact with it, or (*c*) to ensure high contact conductance. A cathodic treatment is described which puts the material in a satisfactory condition for copper plating. Other deposits may then be added as required. The sequence of operations is: (*a*) Degrease, (*b*) give short aqueous alkali electrolytic treatment with the work as cathode, (*c*) give anodic sulphuric acid etch, (*d*) electrolytically etch, as the cathode, in an acid nickel-sulphate solution, and (*e*) copper plate. Full details of solutions, times, and current densities are given.—P. M. C.

Protection and Decoration of Ferrous Metals. J. Liger. (Métallurgie, 1950, vol. 82, May, pp. 403–405, 407; Sept., pp. 705–708). In the first part, the author surveys protective processes used where the finish is of no account. The advantages and drawbacks of the following are discussed: Paints, varnishes, and enamels; galvanizing and tinning; spraying; electrolytic deposition; Sherardizing and Calorizing. In the second part he deals with protection where the final finish is important. Such methods include varnishing, bronzing, light electrolytic protection, nickel and chromium plating, enamelling, and painting.—R. S.

Steel Sheet Plated with Sheet of Another Material by Hot Rolling. (Technische Rundschau, 1950, vol. 42, May 12, pp. 18–21). The method of producing thick steel sheet clad by a hot-rolling process with copper, nickel, or corrosion-resisting steel, applied in a works in West Germany is described. Examples of application are shown, *e.g.*, a nickel-plated autoclave 3200 mm. in dia., and a copper-plated double-walled vessel.—E. G.

Periodic Reverse-Current Electroplating. A. Bregman. (Metal Progress, 1950, vol. 58, Aug., pp. 199, 200, 261–263). Details of Jernstedt's process, which gives superior physical properties and freedom from porosity, are given. The essence of this process is brief reversal of plating current at short intervals, which smooths the previous deposit. Requisite equipment, and operating methods are described. It is pointed out that application of 'P.R. plating' is limited to heavy deposits, and that some of the possible advantages, such as smoothness and plating speed, are mutually exclusive.

E. T. L.

A Survey of the Reflectivity of Some Common Metals and Alloys. A. H. Unckel. (Sheet Metal Industries, 1950, vol. 27, July, pp. 654–658). The relative and absolute reflectivities of a number of pure metals and alloys were determined with a G.E.C. glossmeter. Both polished and mat surfaces were tested, and, for the relative values, polished silver was assumed to have a reflectivity of 100. The effects of wavelength and angle of reflection were also studied, and the complete results are presented in tabular form.—P. M. C.

Chromium as a Wear Preventative. G. H. Jackson. (Scientific Lubrication, 1950, vol. 2, July, pp. 23–24). The advantages of chromium-plated liners are given as hardness, low coefficient of friction, corrosion resistance, and ease of deposition by electroplating. An etched surface is suggested as giving good wear resistance.—J. W. P.

Porous Chrome Plating. (Metal Industry, 1950, vol. 76, Apr. 21, pp. 307–309). Hard chrome plating forms a very desirable working surface for internal combustion engine cylinders. The serious drawback—that the plate is not wetted by oil—has been overcome by roughening the plated surface and so forming channels or pits which retain oil. This surface roughening is accomplished by an etching technique developed by H. van der Horst. Plating thicknesses

vary from 0·004 in. for a small private car engine, to 0·020 in. for marine engines. At least four, and occasionally up to ten times the useful life of cast iron, is claimed for cylinders thus treated. The process is being operated by British van der Horst, Ltd., the article describing the plant layout, equipment, and sequence of operations.—P. M. C.

Effect of Impurities and Purification of Electroplating Solutions I—Nickel Solutions. D. T. Ewing, R. J. Rominski, and W. M. King. (Plating, 1949, vol. 36, Nov., pp. 1137–1145). Methods of assessing the effects of impurities in nickel-plating solutions on the appearance, adhesion, resistance to salt spray, ductility, and hardness of the coating are described.—R. A. R.

Processing Cycles for Chromium Plating. J. L. Bleiweis. (Products Finishing, 1950, vol. 14, May, pp. 38–44). The stages in the application of decorative chromium plating to ferrous, copper, zinc, lead, aluminium, and magnesium alloys, and nickel are very briefly described.—J. P.

"Chromizing." P. Galmiche. (La Recherche Aeronautique: Sheet Metal Industries, 1950, vol. 27, Aug., pp. 749–750). A brief description is given of a process for forming chromium-rich layers on steel, thus imparting corrosion-resistant properties. The process is carried out by the reaction on the iron of a chromium halide, formed during the treatment by the action of an ammonium halide on chromium or iron–chromium. When using mild steel, outer layers containing 50% Cr may be obtained, the outer surface being only slightly harder than the mild steel itself. On high-carbon steels, however, thinner and harder chromium carbide layers are formed, due to the inverse diffusion of carbon. The properties of these layers can be varied by introducing other elements.—P. M. C.

Zinc Plating for Corrosion Resistance and Decorative Purposes. S. R. Goodwin. (Electroplating, 1950, vol. 3, Oct., pp. 524–528). Electrodeposits of zinc confer high resistance to corrosion on ferrous materials and, where appearance is not of prime concern, mat deposits are adequate. Procedures for producing such deposits from acid and cyanide baths are described and some suitable electrolytes are indicated. Zinc can be deposited in a lustrous form and the various methods so far proposed are dealt with, particular reference being made to working difficulties. A new proprietary process known as 'Promat' has recently been introduced to this country from the U.S.A. This process gives deposits hardly distinguishable in appearance from chromium and the baths employed have good throwing and covering power, and can be used at high current densities. The deposits have excellent corrosion resistance.—J. P.

Developments in Galvanizing. F. G. White. (Products Finishing, 1950, vol. 14, May, pp. 48–56). The history of the production of hot-dip galvanizing in the U.S.A. and the advantages of continuous galvanizing, in which the steel strip is superficially oxidized and reduced before it enters the zinc kettle, are briefly described.—J. P.

Bright Zinc Plating from Potassium Cyanide Baths. B. M. Pearson. (Product Finishing, 1950, vol. 3, Apr., pp. 56–59). The use of certain aromatic keto-compounds to act as brighteners in a KCN zinc bath is discussed. Contamination of the zinc deposit is prevented by maintaining a sulphide concentration in the bath adequate to precipitate such metals as lead, mercury, and copper.—J. P.

Construction of a Small-Scale Sheet-Galvanizing Unit. M. L. Hughes and I. E. Thomas. (Journal of The Iron and Steel Institute, 1951, vol. 167, Jan., pp. 46–47). To make a thorough study of the various aspects of the hot-dip galvanizing of sheets, experimental work is required which cannot conveniently be carried out in the works. A small galvanizing unit, enough to hold about 6 cwt. of zinc, has been constructed at the B.I.S.R.A. laboratories at Sketty Hall, Swansea. The unit was designed to galvanize sheets of 8 in. width and of any convenient length, in a manner essentially similar to that employed in industry. After certain initial troubles, mainly due to the inevitable alloying of moving parts, sheets have been successfully galvanized at various speeds, bath temperatures, and bath compositions. This report describes the construction of the unit, and, since it was not possible to base the design on any system of similarity principles, a fairly detailed account is given of the reasoning by which the final dimensions were determined.

A Survey of Coating-Thickness Variation on Commercially Galvanized Sheets. M. L. Hughes. (Journal of The Iron and Steel Institute, 1951, vol. 167, Jan., pp. 48–65). In view of the close relationship between the thickness and the protective value of zinc coatings, an examination of the distribution of coating thickness on representative samples of commercially galvanized steel sheets has been made. The results of measurements along, across, and upon either side of the sheets are reported, and the probable relationship between the different types of thickness variation observed and existing techniques of galvanizing is discussed.

Pot Life in Gas-Fired Galvanizing Settings. A. Higgs. (British Industrial Finishing, 1950, vol. 3, Aug., pp. 43–46; Gas Heat in Industry, 1950, vol. 13, Sept., pp. 373–376). *See* Journ. I. and S.I., 1951, vol. 167, Jan., p. 99.

Fluxing in Hot Galvanizing. A. Gordet. (Galvano, 1949, vol. 18, June, pp. 21–23; Sept., pp. 19–21). The function of salammoniac and of the double salt $ZnCl_2.2NH_4Cl$ in preparing the surface of steel articles for hot galvanizing is discussed in general terms. Particular attention is paid to the elimination of $FeCl_2$ so as to reduce dross formation. A claim is made that by dipping in a boiling solution of the double salt, containing some unspecified 'corrector,' it is possible to precipitate all adventitious $FeCl_2$ as oxide and so prevent it from entering the zinc bath.—J. P.

Sendzimir Process Broadens Galvanized Sheet Applications. (Steel, 1950, vol. 126, June 12, pp. 102–113). **Galvanizing by the Sendzimir Process.** (Blast Furnace and Steel Plant, 1950, vol. 38, Aug., pp. 912–916: Product Finishing, 1950, vol. 4, Aug., pp. 43–66: Metal Finishing, 1950, vol. 48, Oct., pp. 63–68). **Armco Takes Wraps off Sendzimir Galvanizing Process.** K. Oganowski. (Iron Age, 1950, vol. 165, June 8, pp. 71–74). This is an abstract of a paper read before the Galvanizers Committee of the American Zinc Institute at Toronto. The process consists of oxidizing the strip by heating which also removes the rolling lubricants and other combustible material. This oxidized surface is then reduced by heating in a controlled atmosphere, the material being annealed at the same time. The rate of formation of brittle iron–zinc compounds in the coating bath is controlled by the addition of aluminium and the temperature of the material being coated.—A. M. F.

Galvanizing Water Tanks at Hotpoint. J. Wallerius. (Iron Age, 1950, vol. 165, June 15, pp. 110–112). A general description of the automatic galvanizing of tank bodies at the Water Heater Division of the Sunbeam Corporation, Milwaukee, is given.—A. M. F.

Transition from Solid Fuel to Gas for Heating Annealing Furnaces and Galvanizing Kettles. A. Duphorn. (Stahl und Eisen, 1950, vol. 70, July 20, pp. 658–664). Experience obtained over a long period in changing from solid to gaseous fuel for heating furnaces and lead and zinc pots is reported. Besides greater cleanliness of equipment and shops, the most important characteristic of gas heating is increased output with reduced fuel cost as a result of uniform and controllable temperatures.—J. P.

Deep-Drawing Galvanized Steel Retains Corrosion Resistance after Forming. K. Rose. (Materials and Methods, 1950, vol. 31, Feb., pp. 63–64). Galvanizing provides excellent protection against atmospheric corrosion and is adequate for immersion in water. Its use has, however, been limited because subsequent cold forming usually causes some flaking of the zinc coating. A process has been developed by the Armco Steel Corp. which applies a zinc coating which is undamaged by deep-drawing operations. The strip is passed through a furnace having a hydrogen and nitrogen reducing atmosphere, and then into a zinc bath of special composition, in which the formation of the brittle iron–zinc alloy layer is suppressed. Details of this bath are not given but the patents of the process are now available for licence.—P. M. C.

Sherardising: Present-Day Methods and Recent Developments. A. E. Williams. (Mechanical World, 1950, vol. 127, May 26, pp. 579–582). An advantage of this process is that it produces a very uniform coating of zinc with a high resistance to abrasion, making it particularly suitable for use on screw threads. The limitations of economic thickness of coating and size of work are discussed; the process is suitable for small compact articles. A further point is that the mat grey surface forms a key for further protective coatings of paint.—J. W. P.

Causes and Control of White Rusting on Zinc Coated Sheets. G. R. Hoover and A. Thomas. (Regional Technical Meetings

of American Iron and Steel Institute, 1949, pp. 243–251). The formation of white rust on zinc-coated sheets is discussed and methods of reducing or delaying its occurrence are described. White rust is shown to occur most readily when sheet surfaces in contact become wet.—G. F.

Tin Plate. J. N. Crombie. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 129–171). In Part I of this paper, the author discusses some aspects of the manufacture and characteristics of tinplate, with special reference to hot dipped and electrolytic tinplate and factors affecting their use. The mill processing and control of heat-treatment are described, and the requirements of tinplate used in the canning industry are considered, resistance to corrosion being dealt with in some detail. In Part 2, the hot-tinning machine and tinning practice are discussed. Variations in the thickness of the tin coating are considered, and it is emphasized that mechanical roller application of the fluid is not conducive to uniform coating and is further complicated by the presence of iron–tin alloy. Some of the difficulties encountered in attempting to place hot tinning on a more scientific basis are noted.—G. F.

Granite City Steel Co. Completes Strip and Tin Plate Mill Modernization. C. Longenecker. (Blast Furnace and Steel Plant, 1950, vol. 38, Jan., pp. 83–86). The stages in the processing of strip from the strip mill to a Mesta tandem mill are described and details of the production of tinplate are given.—J. P. S.

Tinplate Handbook. W. E. Hoare. (Tin Research Institute, Sept., 1950). This 30-page booklet contains facts about the manufacture, grades, qualities, packing, ordering, testing, and applications of tinplate. There is a glossary of tinplate terms with equivalents in English, French, German, and Spanish.

Hot-Dip Tinning of Cast Iron. W. E. Hoare. (Foundry Trade Journal, 1950, vol. 89, Nov. 23, pp. 411–414, 427). Cast irons intended for tinning are either grey machinable irons, or certain high-duty irons. It is advisable that their carbon contents should not exceed 3·5%; their silicon contents 2·7%, and the phosphorus content may be about 1·3%. The iron when in the as-cast condition is superior in tinning quality to iron which has been annealed, and every effort should be made to ensure a homogeneous and sound casting. For satisfactory results, two principles must be applied: (1) The surface to be tinned must be brought to as clean a condition as possible by mechanical means, and (2) aqueous acid pickling should be avoided if possible. Various methods of tinning are detailed, these being the iron plating method, and the chloride process, which are suitable for small articles, and the chemical oxidation methods, such as the Kolene process and the T.R.I. nitrate process which are employed where high adhesive strengths are required. J. E. W.

Effect of Bath Composition on Aluminium Coatings on Steel. D. O. Gittings, D. H. Rowland, and J. O. Mack. (American Society for Metals, Oct., 1950, Preprint No. 3). Antimony, beryllium, bismuth, cadmium, calcium, chromium, cobalt, copper, germanium, lead, magnesium, manganese, nickel, silicon, silver, tin, titanium, vanadium, and zinc were added individually in various amounts to experimental hot-dip aluminium-coating baths, and the effect of these on the thickness of the alloy layer between the aluminium and the steel base was studied metallographically. Only silicon, copper, and beryllium decreased the thickness more than 50%. Only silicon and beryllium decreased the alloy layer's average microhardness, and they also improved the flat-bend-test performance of the aluminium coating, beryllium more than silicon. Bismuth, calcium, copper, germanium, magnesium, nickel, silicon, tin, and zinc additions destroyed the as-dipped surface of commercially pure aluminium coatings.—E. T. L.

Coating of Steel with Aluminium. S. L. Case. (Steel Processing, 1950, vol. 36, Sept., pp. 435–439, 451). The main objective of aluminium coating is to produce non-scaling surfaces for high-temperature service. Calorizing (a diffusion process); aluminizing (a metal-spraying process); and various hot-dip processes are the most successful industrial methods. The author describes them in detail, and outlines their applications and limitations. Cladding by rolling, vapour plating, and electroplating are also briefly described but are not yet considered to be industrially successful. The comparative resistance to scaling of several calorized and uncoated steels is tabulated, together with the resistance to a hydrogen sulphide atmosphere at 650° C.—P. M. C.

Marine Applications of Cathodic Protection and the Electrocoating Process. H. S. Preiser and B. L. Siverstein. (Journal of the American Society of Naval Engineers, Inc., 1950, vol. 62, Nov., pp. 881–905). If, in the application of cathodic protection to ship's hulls in sea water, the impressed current is increased substantially over its minimum value, a white deposit of calcium and magnesium salts will be plated out on the hull. When the coating is deposited under carefully controlled conditions it can act as a protective coating. It is sometimes known as a 'high current density polarization coating,' 'marine electrocoating,' 'calcareous coating,' and 'Cox coating.' The development of this process in the U.S.A. is reported. Coatings formed with a current density of 100–200 milliamp./sq. ft. are the densest and therefore most desirable. A total current of 6–10 amp.-hr./sq. ft. produces optimum results. The antifouling properties of these coatings are dealt with at length. Electrolytic derusting and descaling are described and the cathodic protection of the interior of petrol and oil tanks, and of ships is discussed. There are 58 references.—R. A. R.

Notes on the Drying of Plated Components. C. D. Leonard. (Electroplating, 1950, vol. 3, Sept., pp. 483–486; Oct., pp. 531–534). Precautions to be observed in the use of sawdust for drying water-washed components are described and the use of a hot-air injected centrifuge for small articles is recommended. Tanks suitable for use with de-watering fluids are illustrated. Some of these fluids merely displace water and then evaporate, while others leave behind a protective film. This may be a thin temporary rust preventive, often with corrosion inhibitors added, or a thicker film which will dry and serve as a base for subsequent painting. Some general precautions to be taken when rinsing and drying components so as to prevent rusting, and staining, are dealt with.—J. P.

Rubber and Its Derivatives as Protective Coatings for Metals. R. F. Reynolds. (Industrial Heating Engineer, 1950, vol. 12, Sept., pp. 288–290). This paper is concerned with the use of rubber and ebonite as protective coatings for metals against chemical attack and abrasion, and with the use of the chlorination and oxidation products of rubber in corrosion-resisting paints. Conditions of their use and examples of their application are described in some detail.—J. A. L.

The Use of Chromates for Inhibiting Corrosion. G. T. Colegate. (Industrial Heating Engineer, 1950, vol. 12, July, pp. 223–225; Aug., pp. 270–271; Sept., pp. 302–303). In the first part of this series, the advantages of using corrosion inhibitors are discussed, and the relative merits of chromates and bichromates considered in detail. In the second part recommendations are given for the use of chromates in evaporation and other industrial coolers, air-conditioning systems, ammonia condensers, and engine and compressor water jackets. In the final part, the use of chromates in refrigerator equipment, boilers, disused equipment, and heating systems is discussed. The author concludes by considering the effect of chromates on the skin.—J. A. L.

Zinc Chromate Pigmented Etch Primers for Metal Finishing. E. E. Halls. (British Industrial Finishing, 1950, vol. 3, Oct., pp. 251–254). In the application of organic finish, adhesion, and its retention for long periods are important. Conditions under which good adhesion can be obtained have been outlined. Some causes of adhesion loss are summarized as follows: Plasticizers may be lost if of too low a boiling point, or may be easily affected by humidity. Under fluctuating atmospheric conditions the cellulose films may become brittle, less flexible, and oxidized. Another cause is the reduction between the base metal and the ingredients of the finishing medium. The author points out various methods of pre-treating the surface of metals before applying a coat.—E. T. T.

Bonderizing for Wire Drawing. (Wire Industry, 1950, vol. 17, Dec., p. 970). A brief description is given of the full-scale Bonderizing phosphate coating plant recently installed by Frederick Smith and Co., Wire Manufacturers, Ltd., Halifax. The plant is believed to be the largest in the world solely devoted to bonderizing of wire. The sequence of operations is: Cold hydrochloric acid pickle, pressure cold water spray, immersion cold running water rinse, immersion bonderizing for 5–10 min. at 155–160° F., immersion cold water rinse, hot lime dip, bake.—J. G. W.

Bonderizing. M. Reeves. (Metal Industry, 1951, vol. 78, Jan. 5, pp. 7–8). Bonderizing is a method of pre-treatment

that provides a corrosion-inhibiting base for subsequent high-class paint finishes. The metal surface is converted into a non-metallic, absorbent, crystalline, phosphate coating. The bonderizing solution may be applied by spray gun or by immersion, and the author gives details of the sequences of operations for both methods.—P. M. C.

Phosphating Plant for Metal Windows. (Product Finishing, 1950, vol. 3, Sept., pp. 46–48). The equipment at the Hooton factory of Williams and Williams, Ltd., Chester, for the automatic treatment of steel window frames provides for the following stages: Caustic soda cleaning, neutralizing, Granodine rust-proofing, chromic wash, and drying. While still on the conveyor, the frames receive priming and finishing coats of stoving enamel and are then delivered to the dispatch department. The fire-extinguishing system is described at some length.—J. P.

The Vapor-Phase Deposition of Refractory Materials. I—General Conditions and Apparatus. I. E. Campbell, C. F. Powell, D. H. Nowicki, and B. W. Gonser. (Transactions of the Electrochemical Society, 1949, vol. 96, pp. 318–333). General conditions and apparatus for applying coatings of the refractory metals, carbides, nitrides, borides, silicides, and oxides by vapour-phase deposition are described. This process consists essentially of reducing, reacting, or decomposing a volatile compound of the coating material at a heated surface. Thick adherent deposits have been obtained on a variety of bases, both metallic and non-metallic. A few of the properties of the deposits are described along with their limitations and potential uses as protective coatings for high-temperature service.

Non-Metallic Lining Materials for Process Vessels in the Pulp and Paper Industry. B. Thomas. (Corrosion, 1950, vol. 6., Mar., pp. 82–88). The relative merits and methods of application of thick (1 in. to 8 in.) ceramic linings and of thin ($\frac{1}{8}$ in. to $\frac{3}{8}$ in.) organic membrane linings are discussed.

O. H. G.

Aluminium Coating of Steel—A Comparison of Various Processes. P. T. Stroup and G. A. Purdy. (Metal Progress, 1950, vol. 57, Jan., pp. 59–63). This is a comparison of hot dipping, cladding, electroplating, spraying, chemical reaction, and calorizing. This shows that aluminium coating is feasible, but some development work is still needed, in particular to avoid an interfacial layer of non-aluminium compound.

E. T. L.

Brighter Finishes with "PR" Plating. G. W. Jernstedt. (Steel, 1950, vol. 126, May 1, pp. 86–88, 108–116). Periodic reverse current electroplating together with a new metallic inorganic addition agent called Wes-X has enabled the Westinghouse Electric Corporation, Pittsburgh, to bright-copper-plate with, in many cases, the elimination of buffing. This addition agent is not subject to decomposition products and activated carbon can be used to remove extraneous organic material. The reversing current produces a fine grain structure by interrupting growth.—A. M. F.

Electrolytic Impregnation of Steels with Silicon. M. Dodero and P. Blum. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1950, vol. 47, July, pp. 544–546). A brief revue of normal methods of impregnation is given. In the electrolytic process the steel is made the cathode in a bath of sodium silicate and fluoride. With increasing current density the compounds Fe_3Si, Fe_5Si_2, FeSi, and $FeSi_2$ are obtained. Details of the treatment of an Armco iron are given with corrosion test results. Two distinct zones are produced, the outer one brittle, the inner coherent and corrosion resistant.

End Point Indication of the B.N.F. Jet Test for Measurement of Thickness of Cadmium Coatings on Steel. S. G. Clarke and J. F. Andrew. (Journal of the Electrodepositors' Technical Society, 1950, vol. 25, p. 39). When the contrast in appearance between the cadmium and the steel exposed in the coating thickness test is insufficient to show the perforation point clearly, one or two drops of a solution consisting of mercuric chloride 10 g., conc. hydrochloric acid 50 ml., and water to 100 ml., applied on the test spot will give a clear indication.

R. A. R.

Solid-Phase Bonding of Aluminium Alloys to Steel. V. W. Cooke and A. Levy. (Journal of Metals, 1949, vol. 1, Nov., pp. 28–35). Three procedures for solid-phase bonding of aluminium alloys to various chromium–nickel steels, involving respectively twisting, shearing, and hot-pressing, are described and shown to be capable of producing high bond strengths. The twist and shear methods are characterized by low bonding temperatures and considerable deformation, the hot-press method involving higher temperatures and no external lateral movement. The effects of bonding temperature, pressure, surface preparation, deformation, composition, and subsequent heat-treatment on the resulting bond strengths are investigated. In all cases, the bond strength was increased by subsequent annealing by as much as 100%.

G. F.

Recommended Practices for Metallizing. (American Welding Society, 1950, C2.1-50T). This is the first of a series of metallizing standards. It is in two parts: IA—Metallizing Shafts or Similar Objects; II—Metallizing—Safety Recommendations.—R. A. R.

Determination of the Temperature of Sprayed Metal Particles. J. E. Cline, R. T. Thurston, and J. Wulff. (Welding Journal, 1950, vol. 29, July, pp. 320s–322s). The authors describe the development of an experimental technique for determining the heat content and temperature of sprayed metal particles at the moment of impact. The investigation includes tests made with zinc, aluminium, copper, nickel, iron, and molybdenum. Results obtained indicate that the metal particles are at their melting point at impingement. Calculations are included to show that the contribution of the kinetic energy to the heat content and temperature of the particles is a negligible quantity.—U. E.

Metal Spraying of High-Temperature Metals and Alloys. R. T. Thurston and J. Wulff. (Welding Journal, 1950, vol. 29, July, pp. 313s–319s). The results of an investigation of the metal spraying of high-temperature metals and alloys are presented. A hydrostatic bursting technique was developed as a means of measuring the strength of sprayed deposits. With this technique, a relationship was shown to exist between the oxide content and strength of sprayed metal. Sintering of sprayed metal deposits in hydrogen, especially in the presence of a liquid phase, was successfully accomplished, resulting in significant increases in density and bursting strength.

U. E.

Sprayed Metal Coatings Improve Corrosion Resistance of Wide Range of Products. J. E. Wakefield. (Materials and Methods, 1950, vol. 31, Apr., pp. 67–69). The article describes how sprayed metals, particularly zinc and aluminium, are being applied to finished products as corrosion preventatives. The versatility of the metallizing gun is illustrated by reference to three types, one purely manual, one semi-automatic, and one completely automatic. The cost and speed of metallizing with aluminium, zinc, lead, tin and antimony–lead are discussed and also tabulated. Another table shows the life expectancy of zinc and aluminium coatings of various thickness when exposed to the following corrosive conditions: Rural, industrial, and salt atmospheres, and fresh and salt waters.—P. M. C.

A Survey of the Metal Spraying Industry. D. E. Harris. (Australasian Engineer, 1950, Apr. 6, pp. 52–55). The principle of the metal-spraying pistol is described, and the applications of sprayed coatings are outlined. In the pistol, wire is melted, atomized, and the particles driven by compressed air on to the surface being metallized. Wire sizes range from 0·080 in. to 0·125 in. and deposition rates from 27 lb./hr. for zinc to 4 lb./hr. for steel. Owing to the cooling action of the air blast, there is very little heating of the surface. Non-metallic surfaces can be metallized quite satisfactorily. No alloying or chemical bonding occurs between a metal base and the sprayed coat, yet the adhesion is extremely satisfactory. Zinc and aluminium are used extensively for resisting corrosion by fresh water, sea water, and the atmosphere. Water storage tanks, structural steelwork, and even ships' hulls have all been treated successfully. Corrosion at high temperatures is also reduced by an aluminium coating which has been heat-treated to form an alloy with the base metal.

P. M. C.

Metal Spraying. W. Kaspevowicz. (Przeglad Techniczny, 1950, May, pp. 247–250). [In Polish]. Spraying guns, surface preparation for spraying, structure of sprayed metal, and the industrial importance of metal spraying are surveyed.

Porcelain Enamels. H. R. Clauser. (Materials and Methods, 1950, vol. 31, Feb., pp. 71–82). Because of their high durability, excellent corrosion resistance, and attractive appearance, porcelain enamels are becoming increasingly important as coatings for metals. They are glass-like materials,

composed of inorganic mineral matter, and are fused on to base metals at temperatures in the region of 1500° F. The first section of the article describes in detail the characteristics which can be produced to meet specific requirements. The second section describes the different types of enamel, the most important advance in recent years being the development of those containing titanium dioxide. Methods and enamels have also been developed for coating aluminium. The final section surveys the types of stock which can be satisfactorily coated, the most suitable one to date being a specially made titanium enamelling steel, containing 0·06% C, 0·30% Mn, 0·01% P, 0·03% S, 0·10% Si, and 0·30% Ti. P. M. C.

Cobalt and Nickel in the Vitreous-Enamelling Industry. J. E. Hansen. (Institute of Vitreous Enamellers: Sheet Metal Industries, 1950, vol. 27, Apr., pp. 363–368). Typical analyses are quoted of commercially available grades of Co_3O_4, $CoSO_4.7H_2O$, NiO, and $NiSO_4.6H_2O$. Whilst these compounds act as colouring agents, their main function is greatly to improve the adherence properties of ground-coat enamels. Reference is made to many papers dealing with the mechanics of enamel adherence, one of the main requirements being the presence of a film of iron oxide on the sheet which is partially dissolved in the enamel during firing. Cobalt and nickel oxides apparently increase the solubility of iron oxide in the enamel, typical additions being 0·5 to 0·63% of Co_3O_4, and 0·0 to 1·23% of NiO. The sulphates of cobalt and nickel are used for decorative mottling. Adherence properties can also be improved by giving the material a nickel 'dip' before applying the enamel, especially if this is of the white variety free from cobalt.—P. M. C.

Some Aspects of Corrosion Prevention in Practice. W. Montgomery. (Sheet Metal Industries, 1950, vol. 27, July, pp. 643–653). Barffing, vitreous enamelling, and galvanizing are three typical methods of protection applied industrially to ferrous products. Barffing consists of coating the article with a film of Fe_3O_4 by a reaction with superheated steam at 800° to 850° C. The applications and performance of the method are reviewed. The author gives the composition of a blue borosilicate glass enamel developed by himself, and describes in some detail the causes of fish-scaling and blistering. Electrical tests for impermeability are briefly reviewed. Finally, hot-dip galvanizing is discussed with particular reference to surface preparation and composition of base metal, and to the corrosion resistance of galvanized coatings.—P. M. C.

Fusing of Enamels. J. A. Clarke. (Foundry Trade Journal, 1950, vol. 88, Apr. 6, pp. 371–376). After discussing furnace design, instruments, atmospheres, refractories, and operational methods, the results of practical fusing tests for varying times on standard metal samples are given. The tests indicate that gas liberated from the metal causes some disturbance of the 'biscuit' and this liberation of gas continues with some violence until fusion of the enamel to a very viscous state occurs. From temperature measurements it is concluded that gas evolution is at a maximum up to about 700° C., after which it gradually ceases. Also at this temperature the reactions in the enamel layer itself become evident.—J. E. W.

Drying by Infra-Red Rays. K. P. Osminkin and A. F. Burmistrowa. (Przeglad Techniczny, 1950, July–Aug., pp. 383–384). [In Polish]. The description of an infra-red ray drying installation for painted metal articles is given.—V. G.

Applications of Electrostatic Spraying and Detearing in Metal Finishing. J. Stribley. (Sheet and Strip Metal Users' Technical Association: Sheet Metal Industries, 1950, vol. 27, May, pp. 460–466). In the electrostatic-spraying process, which is entirely automatic, the articles to be painted are carried on an earthed conveyor through a coating zone where a highly ionized electrostatic field is created between them and an adjacent electrode system, which is charged to a negative static potential of 130,000 V. Atomized paint is sprayed at low velocity into this field between the electrode and the articles, and, becoming negatively charged through electron collision, the paint is deposited on the earthed articles. Superior finishes and up to 50% saving on paint consumption are two of several advantages over manual spraying. Detearing, *i.e.*, the removal of excessive paint which collects at drain-off points after dipping processes, is accomplished by passing the articles over a massive electrode, charged in such a manner that the globule of paint is drawn off in the form of a fine spray until the normal film thickness is obtained. The author gives details of plant required, its layout, power supplies, safety precautions, and a discussion of the advantages and disadvantages of the methods.—P. M. C.

Fume Elimination for Wire Enameling Ovens. R. J. Ruff. (Wire and Wire Products, 1950, vol. 25, Feb., pp. 131–132, 172–173). The application of catalytic incinerators to the exhaust from existing wire-enamelling ovens is discussed. The fumes containing vapours given off by cresylic acid, naptha thinners, and other hydrocarbons are noxious atmosphere polluters and also cause rapid clogging of exhaust manifolds and increased fire hazards. Several methods such as flame incineration and water-scrubbing are costly in fuel equipment and reintroduce difficulties of disposal. The function of the catalyst in the catalytic incinerator is to depress the auto-ignition temperature of the hydrocarbon fumes to 500° F. which is the exhaust temperature of wire-enamelling ovens. The incinerator consists of a steel-plate housing with a cylindrical alloy frame carrying two concentric container screens $\frac{1}{2}$ in. to 2 in. apart, the gap being filled with the catalyst, and capped with a conical baffle which ensures thorough mixing of fumes with catalyst. An incinerator of this type has operated 2000 hr. in a Formvar enamel baking oven without maintenance. Thermocouples recorded a temperature of 490° to 510° F. at entry to the housing and discharge temperature of 850–950° F. Since the combustion of the fumes is an exothermic reaction, no external heating is required. J. G. W.

Screwthreads with a Protective Anti-Corrosive Coating. N. Karpenko. (Strojnický Obzor, 1950, vol. 30, Apr., pp. 61–64). [In Czech]. Attention is drawn to the possibility of saving higher priced materials by applying anti-corrosion coatings on screwthreads. The various methods of obtaining anti-corrosive coatings are briefly described and information is given on the permissible dimensional tolerances for threaded parts so treated.—E. G.

POWDER METALLURGY

Production of Metal Powders. E. Mehl. (Metal Treatment and Drop Forging, 1950, vol. 17, Summer Issue, pp. 118–122, 124, 126, 128). The electrolytic deposition of metals from aqueous solutions is described, special consideration being given to the production of copper and iron in powder form. The processes are simply adaptations of normal electroplating methods, arranged to produce either (1), loose spongy deposits which give powders directly or (2), dense, brittle deposits which need crushing and grinding. Copper is usually deposited as a sponge from straightforward $H_2SO_4/CuSO_4$ solution, higher current densities and lower copper concentrations and temperatures being used than in electroplating. Both compositions and deposition conditions for six typical processes are tabulated, and the washing and drying procedures are outlined. Iron may be deposited either as a powder directly or as a brittle compact, many different processes being in use without any one having established its superiority. Chloride baths are more widely used than sulphates, and the author briefly describes the main features of 13 known processes. The production of zinc, nickel, tin, and lead in powder form is also referred to. There are 36 references.—P. M. C.

Powder Metallurgy and Lubrication. H. W. Greenwood. (Scientific Lubrication, 1950, vol. 2, Apr., pp. 2–4). The properties and uses of porous bearings made of iron, steel, bronze, and copper–lead, are reviewed. Reference is also made to Porosint filters.—J. W. P.

The Rôle of Powder Metallurgy in the Brazilian Metals Industry. V. Chiaverini. (Mineração e Metalurgia, 1950, vol. 15, May–June, pp. 18–22). [In Portuguese]. The requirements giving rise to the application of powder-metallurgy techniques are stated. The well-known processes and phases of production of metal powder are mentioned and the following products are discussed: Refractory metals; hard metals; porous materials; materials for electrical contacts; magnetic materials; and wear-resisting materials.—R. S.

Suitability of Zirconium and Thorium Carbides for Sintered Hard-Metal Alloys. R. Kieffer. (Metall, 1950, vol. 4, Apr., pp. 132–135). The author prepared ZrC and ThC_2 by carburizing the pure oxides with soot, and tested the simple carbides and the mixed carbides of zirconium with vanadium, niobium, tantalum, molybdenum, and tungsten as to their suitability for sintered hard metal alloys used in cutting tools. From a comparison of alloys in which these carbides were

substituted for titanium carbide in the standard alloys S1, S2, and S3 (78% WC, 16% TiC, 6% Co; 75·5% WC, 16% TiC, 8·5% Co; and 87·5% WC, 4% TiC, 8·5% Co respectively), the author concludes that thorium carbide is unsuitable; zirconium carbide alone is suitable but the resulting alloys are inferior to the standard ones, and that the mixed carbides produce alloys of equal quality provided the proportion is 1·7 to twice that of the titanium carbide. The comparison is based on hardness measurements and on machining tests. Details of X-ray analyses and of the sintering procedures are given.—J. G. W.

PROPERTIES AND TESTS

Mechanical Testing and Research on Strength of Materials in Germany from 1939 to 1949. E. Siebel. (Schweizer Archiv, 1950, vol. 16, Apr., pp. 97–114). After reviewing the origin and development of the German materials testing establishments, with special reference to the last decade, certain recent German and Swiss papers on strength and testing of materials under static and dynamic stresses are discussed. These papers deal with the behaviour of materials under non-uniform static stress systems; the stress distribution in dished ends of boilers; and the effects of damping and stress gradient on the behaviour of materials under non-uniform dynamic stress systems and on the size effect in fatigue testing.—H. R. M.

The Practical Meaning of Mechanical Test Results. O. A. Klein. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 357–369). Some of the tests designed to predict the behaviour of steel in practice are discussed and some possible changes which could be made in steel specifications are indicated. The author discusses the choice of tests for particular circumstances, and explains the significance of tensile results, elongation, reduction in area, bend tests, hardness tests, and impact values. The correlation of test results with performance and some of the difficulties encountered in testing are outlined.—G. F.

Plastic Deformation in Iron and Mild Steels. Ch. Boulanger. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1950, vol. 47, July, pp. 547–557). An investigation of the peculiarities of the load extension curves of iron and low-carbon steels was made. These are: (*a*) A raised elastic limit after a level region with deformation confined to localized bands; (*b*) discontinuities in the curve first observed by Portevin and Le Chatelier in aluminium alloys (these were termed 'blue brittleness'); and (*c*) ageing after tempering or work hardening. Fine wire specimens were tested over a range of temperatures in a micro tensile machine of low inertia. With pure iron the above effects are absent but reappear with the addition of oxygen, carbon, or nitrogen. These elements give, with α-iron, minute amounts (about 0·01%) of solid solutions responsible for the peculiarities observed. A general interpretation of these is given in terms of the normal deformation mechanism, the stress due to allotropic changes, and the physical chemistry of atom diffusion. A rapid examination of other alloys suggests that these properties represent only particular cases of the general behaviour of metals—A. G.

Long or Short Test Pieces for Tensile Testing of Cast Iron? H. Jungbluth. (Stahl und Eisen, 1950, vol. 70, Aug. 17, pp. 742–745). In order to economize in material, the use of short test pieces for tensile testing of cast iron has frequently been proposed. Distribution curves of frequency against tensile strength of about 1000 samples made according to American, Swedish, and German standards and including long and short pieces have been plotted. No conclusions are drawn from the work, which is to be presented to the International Committee for the Unification of Test Methods for Cast Iron. [An English translation appeared in Foundry Trade Journal, 1950, vol. 89, Dec. 28, pp. 559–562].—J. P.

Brittle Failure and Size Effect in a Mild Steel. K. J. Stódden and E. P. Klier. (Welding Journal, 1950, vol. 29, June, pp. 303s–310s). It has been generally accepted that the physical properties of mild steels are highly affected by the size of the test specimen. Thus with reference to the inception of brittle failure, it is believed that for increasing specimen size the temperature is increased at which brittle failure may be encountered. Assuming the validity of this, it is evidently very difficult to rationalize service behaviour of a mild steel with small-scale test results. In the present work an effort is made to show that under certain experimental conditions the phenomenon of size effect can be practically eliminated as it pertains to the appearance of brittle failure. The specimen sizes studied ranged from the 10 × 10-mm. Charpy bar to a 1¼ × 1¼ in. bar tested in slow bending. For these specimen sizes the transition temperature for a mild steel remained constant.—U. E.

Effect of Temperature of Cold Rolling, Temperature of Testing and Rate of Pulling on Tensile Properties of Austenitic Stainless Steels with Low Nickel Content. R. A. Lincoln and W. H. Mather. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 57–74). An investigation into the tensile properties and cold-rolling characteristics of austenitic stainless steels containing 18% Cr and 7% Ni is described. The results show that, when the steel is rolled at a temperature greater than 180° F. and tested at room temperature, higher ductility is obtained than when the steel is rolled at room temperature to the same yield strength. Increasing the rate of tensile testing at room temperature and increasing the testing temperature have similar effects in that the elongation is decreased, this decrease being smaller when the rolling temperature is greater than 180° F. The results are explained on the basis of the known equilibrium relationships.—G. F.

Effect of Temperature on the Modulus of Elasticity. C. W. Andrew. (Metal Progress, 1950, vol. 58, July, pp. 85–89). Several references are given to previous measurements of dynamic elastic modulus, with descriptions of apparatus including a specimen bar supported on two threads, which in turn hangs from a loudspeaker and gramophone pick-up, respectively. The modulus was found by altering the frequency of the input until the rod resonated, when the output was a maximum. The specimens were various steels and aluminium, and the results were obtained up to 1800° F. (1000° C.), showing a fall from about 30 lb./sq. in. at 100° F. to about 17 lb./sq. in. for steel. The article ends with suggestions for future work.—E. T. L.

The Modulus of Elasticity—A Review of Metallurgical Factors. J. E. Dorn and T. E. Tietz. (Metal Progress, 1950, vol. 58, July, pp. 81–84). The author considers the effect of temperature on many metals including iron, where the modulus of elasticity decreases from 30 lb./sq. in. at 100° C., to about 17 lb./sq. in. at 900° C. More results of Köster show the regular variation of the modulus with atomic structure, and with percentage of alloying elements. Elasticity is insensitive to structure, but is affected by cold work.—E. T. L.

Influence of the Velocity of Loading of the Testing Machine on the Tensile Strength of Cast Iron. Application of Statistical Methods to the Interpretation of Results. J. Gélain. (Fonderie, 1950, Feb., pp. 1933–1940). The cast iron selected for these investigations had a tensile strength of 24 kg./sq. mm. on 20-mm. thick bars. It was made in the electric furnace to the following analysis: Total carbon 3·32%, Si 1·88%, Mn 0·73%, P 0·15%, and S 0·05%. It was cast in green sand in bars 30, 20, and 12 mm. in dia., in lengths of 500, 400, and 120 mm. respectively. The reliability of the results of the tests on the Amsler machine is evaluated statistically by applying Henry's law.—R. S.

New German Standards Drafts for the Tensile Test as Applied at Room Temperature to Metallic Substances. N. Ludwig. (Metall, 1950, vol. 4, Mar., pp. 91–100). The article deals with DIN 50145, 50146, and 50125, drafts of which have recently been confirmed. These standards are concerned with definitions and symbols; test procedure and computation of results; and test pieces respectively. They replace DIN 1605, sheet 2 (edition 2, 1936) and DIN Vornorm VDM 125 (edition 2, 1940). With regard to symbols, DIN 50145, continues the practice of using Greek letters for yield stress, ultimate tensile stress, etc., but some terms have been changed (*e.g.*, *Höchstlast* replaces *Bruchlast* for ultimate tensile stress).

The Theory of the Discontinuous Yield Point. B. A. Bilby. (Sheet Metal Industries, 1950, vol. 27, Aug., pp. 707–718). The author gives a brief review of the more important work which has been carried out on this subject. The upper and lower yield point phenomena are discussed, and the early theories of impurities separating to grain boundaries or within ferrite grains are described. The more recent dislocation theory of plasticity, and the idea of dislocation 'atmospheres' are next outlined, followed by a discussion of the yielding and strain ageing of iron. There are 48 references.—P. M. C.

A Research into the Relation between Tensile Tests and the Deep-Drawing Properties of Metals. C. Arbel. (Sheet

Metal Industries, 1950, vol. 27, Nov.–Dec., pp. 921–926). This is an English version of a report which appeared in Revue de Métallurgie, Mémoires, 1950, vol. 47, May, pp. 388–394 (*see* Journ. I. and S.I., 1950, vol. 166, Oct., p. 160).

Tensile Properties of Ingot Iron at Low Temperatures. G. W. Geil and N. L. Carwile. (Journal of Research of the National Bureau of Standards, 1950, vol. 45, Aug., pp. 129–147). True stress–strain curves obtained in tension tests at temperatures ranging from − 196° to + 100° C. with ingot iron as annealed, normalized, quenched and tempered, hot-rolled and cold-drawn are presented. Numerous simultaneous load and diameter measurements were made during the entire course of each test. The effects of previous thermal and mechanical treatment of the iron on the true stress–strain relations are discussed. Graphs are presented showing the influence of the testing temperature, the ferrite grain size, and the initial condition of the iron on the work-hardening characteristics, namely, strain-hardening and strain-ageing. The effects of the above factors on yield stress and ultimate stress, and on true stress and true strain at maximum load and at fracture, are presented. The twinning of iron in the tests at low temperatures is briefly discussed.

Influence of the Rate of Loading on the Properties of Malleable Cast Iron. J. Gélain. (Fonderie, 1950, Oct., pp. 2205–2208). With malleable irons, the rate of loading remains constant only up to the elastic limit. As soon as permanent set is evident and until rupture, the speed of application of the load decreases and is no longer regular. In the present investigations, the loading range started from the load at which the indicator clearly begins to move and ended just below the elastic limit. The loading rates studied varied from 0·16 to 2·15 kg./sq. mm./sec. which, for loads of 500 to 4500 kg., corresponds to periods of 115 to 9 sec., and to total testing times of the order of 6 min. to 20 sec. The rates of loading are related to the elastic limit, tensile strength, and elongation. It was shown that the rate of loading has practically no effect on maximum stress and elastic limit, and no correlation was shown between the rate of loading and the elongations.—R. S.

Physics in the Iron and Steel Industry (7)—The Fracture of Metals. P. Feltham. (Iron and Coal Trades Review, 1950, vol. 161, Aug. 25, pp. 399–403). The author presents a theoretical consideration of the mechanisms of brittle and ductile fracture, and discusses the significance of ultimate tensile stress. Notch and temper brittleness of steel are briefly considered, and it is pointed out that the criteria of ductile fracture are relatively highly dependent on temperature compared with brittle fracture. Technical fracture criteria are considered and the limitations of Fridman's three-dimensional fracture diagram are indicated.—G. F

Effect of Shot Peening on the Brittle Transition Temperature. N. Grossman. (Metal Progress, 1950, vol. 58, Sept., pp. 352–354). Notched specimens of a mild steel were subjected to slow bend tests, with or without previous shot-peening. It was found that shot-peening markedly reduced the temperature at which brittle fracture was replaced by ductile fracture. It was found that there was no correlation between surface hardness of the specimens, and the change in ductility.

An Account of M. Henri M. Schnadt's Ideas on the Strength of Materials and His Testing Methods. R. Weck. (Transactions of the Institute of Welding, 1950, vol. 13, Apr., pp. 41–56). The author describes a new method of testing materials as developed by H. M. Schnadt. This consists of a set of five notched bending specimens of different geometrical properties to be broken in a Charpy machine. The compression zone in each specimen is drilled out and replaced by a tungsten carbide pin, thus preventing almost entirely the absorption of energy in this zone. All specimens are broken in two and the energy absorbed is plotted against the initial plastifying power which is not related to the material, but is simply a property of a state of stress. The application of the new test method to welding is discussed and a mathematical treatment of stress–strain relations is given.—U. E.

The Influence of Oxygen, Nitrogen and Carbon on the Impact Strength of Iron and Steel. J. D. Fast. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 171–183). [In English]. Mild steel was freed from oxygen and nitrogen by high-frequency melting. Known quantities of the two elements were added. Practically pure iron was also prepared and known quantities of impurities were added. The melting equipment is described. The ingots were forged, normalized, and cooled to 20° C. Where oxygen was added, normalizing was done in argon; where nitrogen was added, normalizing was effected in a nitrogenous atmosphere. Charpy tests were made on notched bars. Nitrogen in amounts up to 0·030% by wt. has no effect on the impact strength of normalized mild steel at 20° C. Oxygen, in even greater quantities, has no great effect upon the impact value at 20° C. of mild steel and of pure iron, provided there is more than 0·002% by wt. of carbon present. In the absence of carbon, oxygen has a very harmful effect. A method is described for determining very minute quantities of carbon in steel. The oxygen present at the crystal boundaries in the form of iron oxide causes brittleness. Carbides along the crystal boundaries do not have this effect, probably because a continuous skin is not formed. Impact values as a function of temperature seem to indicate that, even when carbon is present, oxygen can have a harmful effect on impact strength. Nitrogen appears to have the same effect, but gives a flat minimum in the curve for iron at about 400° C., although mild steel without nitrogen shows a minimum impact value at about 500° C.—R. S.

Stress Distribution in Notched Bar Impact Specimens. A. Krisch. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Nov.–Dec., pp. 403–411). In order to determine the course of plastic deformation in Charpy test pieces, the distortion of a rectangular grid ruled on the root of the notch was measured after testing at different impact values. The dimensions of the test pieces were 30 mm. × (5–30) mm. × 160 mm. The deformation perpendicular to the root of the notch was calculated by means of the law of volume constancy. The deformation in the direction of the length of the specimens was always the greatest; the difference between the deformation in the other two directions increased with increasing width of specimen. Assuming that the modulus of plasticity was independent of the state of stress, the stresses at the root of the notches were calculated from these deformations. Because of the coarseness of the measuring technique these stresses were approximate only, but were in general agreement with theoretical expectations. With narrow specimens, when the principal longitudinal stress was over 80 kg./sq. mm., the principal stress in the direction parallel to the notch was only 10–20 kg./sq. mm., while the third principal stress was zero. This represents essentially a condition of uniaxial stress. Disregarding edge effects, the ratio of the principal stresses was dependent on the shape of the test pieces, so that a mean stress ratio could be given. This showed approximately the same dependence on mass as does the impact strength, so that this stress ratio can be set in relation to the danger of fracture, with the limitation that at small distances from the surface unfavourable conditions can arise from the presence of the third principal stress.—J. P.

Three Low-Alloy Steels, Austempered *versus* Oil-quenched. R. L. Rickett and F. C. Kristufek. (Metal Progress, 1950, vol. 58, Sept., pp. 325–328). Experiments on the impact strength, tensile strength, endurance limit, and elongation of specimens either austempered, or quenched and tempered, show that they have similar properties. Austempering low-alloy steels produces bainite, and oil-quenching with subsequent tempering gives martensite, which has similar properties for the same hardness.—E. T. L.

Yield Point and Ageing in Soft Steel. G. Masing. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Sept.–Oct., pp. 315–323). According to the atomistic concept of plastic deformation, it must be assumed that slip involves the co-operation of dislocations, *i.e.*, distortions in the atomic lattice. One part of the lattice does not slide bodily over the other, but a dislocation migrates along the slip plane and so produces a step-wise displacement. The stress concentration around a static dislocation interacts with other dislocations; according to their type there is attraction or repulsion between them. This offers an explanation of the work-hardening of deformed metals. Dislocations are present in all metals, particularly in the transition regions between mosaic blocks or crystallites. The stress around a dislocation in an interstitial solid solution of carbon in iron alters the distribution of carbon atoms; they diffuse towards the dislocations and reduce the stress, so making for a more stable condition. There is thus a higher concentration of carbon around a dislocation than the average of the metal as a whole; the dislocation has surrounded itself with a carbon atom

atmosphere. There is interaction between a dislocation and its carbon atmosphere since the migrating dislocation endeavours to take its atmosphere with it or, alternatively, the atmosphere tends to prevent the movement of the dislocation. The movement of the dislocation is controlled by the deformation velocity and that of the atmosphere by the diffusion rate of carbon. Since both of these are temperature-dependent, their interaction must also vary with temperature. If the velocity of deformation is great compared with that of diffusion at the relevant temperature, the dislocation can detach itself from its atmosphere after overcoming an initial resistance. The migration of the dislocation, and therefore deformation, can take place easily. This is what happens at the yield point. A number of objections to this concept of the yield point of undeformed steel are discussed. At higher temperatures, where the rates of diffusion and deformation are of the same order, the dislocation must drag its atmosphere with it. This makes the movement of the dislocation more difficult and produces an increase in strength such as occurs at blue heat. After plastic deformation at room temperature, the dislocations are detached from their atmospheres and there cannot be a pronounced yield point. After standing, the atmospheres reform around the dislocations and the yield point returns. This is the explanation of ageing according to present concepts.—J. P.

Plastic Deformation of Metals—Survey of Literature 1946–1949 Inclusive. J. L. Hull and I. Cornet. (American Iron and Steel Institute, Nov., 1950, Contributions to the Metallurgy of Steel, No. 38). This 352-page book contains 1500 abstracts from the literature on plastic deformation. They are classified into 20 sections and provided with both subject and author indexes.—R. A. R.

Mutual Relationships between the Stress Gradient and the Deformation Gradient. I—Hindering Plastic Distortion. F. Bollenrath and A. Troost. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Nov.–Dec., pp. 431–436). In this mathematical paper the resistance, dependent on size, to permanent deformation of the distorted parts of polycrystalline metal bodies with unevenly distributed stress and deformation is discussed and formulæ for calculating it described, using as an example the slip of linearly distorted slip planes (*e.g.*, bending at above the limit of proportionality).—R. A. R.

Influence of Small Cold-Rolling Stresses on the Mechanical Properties of Sheet Steel. F. Eisenkolb. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, May–June, pp. 197–201). Experience of the effect of 'skin-passing' on the reduction of yield point and breaking elongation, and the increase of tensile strength and deep-drawing properties of sheet steel are described. It was found that with low-carbon steels the yield point was lowered and the extension at yield point virtually eliminated by 1% cold reduction after annealing, but that the tensile strength and breaking elongation were not significantly changed. The nature of the annealing treatment, the shape of the test piece and the chemical composition (provided that the carbon content was low) did not affect this result. The cold-rolled sheet had better deep-drawing properties than the annealed material and did not exhibit stretcher-strain markings. Reductions of more than 1% caused the yield point to assume a value as high as, or higher than, that of the unrolled material. Ageing of the 1% reduced sheet at 200° C. for 8 hr. also increased the yield point and reduced the deep-drawing properties. It is assumed that the small amount of cold work loosens the grain boundaries and the slip planes and thus allows flow to occur at a lower applied stress. This reduction of yield point is obviously of advantage in deep-drawing.—J. P.

Mechanical and Material Variables Affecting Correlation. C. E. Hartbower and W. S. Pellini. (Welding Journal, 1950, vol. 29, July, pp. 348s–360s). Mechanical and material variables affecting the correlation of performance between small-scale specimens and complex structures have been investigated. Test results on **V**-notch Charpy, nick-bend specimens, and 9-ton box girders show that the concept of rigorous definite correlation between the performance of a simple laboratory specimen and full-scale structure is not feasible. The various specimens, criteria, and attending definitions indicated transitions ranging from approximately −80° to 200° F. for the girder material, whilst the box girder itself resisted fracture at 40° F. The two factors, mechanics and material, which together determine performance are parametrically related and should be investigated in strict recognition of this fact.—U. E.

Origin and Propagation of Cracks in Hardened Steel with Multiphase Structure. V. A. Pavlov and M. V. Yakutovich. (Zhurnal Tekhnicheskoi Fiziki, 1949, vol. 19, No. 4, pp. 465–470). The reasons for the reduced notched-bar toughness of a steel with a martensitic structure when inclusions of a 'plastic' nature (troostite, bainite, or ferrite) are present were studied using three low-alloy steels (C 0·34%, Si 3·97%, Cr 1·41%; C 0·55–0·65%, Si 1·5–2·0%, Cr 0·30% max., Ni 0·30% max.; C 1·3–1·5%, Cr 1·30–1·6%; Ni 0·25% max.) heat-treated to produce different structures. The reduction in toughness is caused either by the plastic deformation being confined to the 'plastic' constituent if the latter is in thin layers in the grain boundaries, or by overstraining of a 'brittle' constituent surrounding the 'plastic' constituent if the latter is spheroidal.—R. A. R.

The Importance of Plasticity in the Phenomena of the Rupture of Metals. O. L. Bihet. (Revue de la Soudure, 1950, vol. 6, No. 1, pp. 20–30). The failures of welds are briefly discussed and the influence of temperature and ductility examined. A detailed review is made of the different theories of failure in metals and the notion of dislocations is introduced and developed. Taylor, Orowan, Dehlinger, and Burgers' interpretations are discussed. A study is made of the work-hardening of metals subjected to torsional stresses and of the resulting brittleness. From this investigation it would appear that the behaviour of metals should be examined in the light of three separate deformational classifications: the elastic, anelastic, and plastic. These terms are defined and failures in these ranges are discussed. Lastly, the author applies the results obtained as a guide in the selection of the best steels for welding.—M. D. J. B.

Plastic Deformation of Cementite in Steel. B. G. Livshits and B. N. Orlov. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 70, No. 2, pp. 229–230). The authors describe cold-rolling experiments on plates of a eutectoid carbon steel (C 0·83%) in which subsequent micro-examination of the structure revealed numerous zones where the cementite plates had undergone pronounced bending instead of breaking up.

Physics in the Iron and Steel Industry (4). Dislocation Mechanism of Plastic Deformation in Metals. P. Feltham. (Iron and Coal Trades Review, 1950, vol. 161, July 14, pp. 69–79). The author first reviews the work of earlier theorists, including Taylor, Orowan, Polányi, and Burgers, and shows how the theory of plastic deformation of polycrystalline metals has been developed from that of single ideal crystals. In the light of these theories, the author then shows how minute traces of impurities affect the mechanical properties of metals, noting in particular the phenomena of yield and blue brittleness in mild steel, and explains the function of annealing and recrystallization. The importance of the rate of plastic deformation is also discussed.—G. F.

Physics in the Iron and Steel Industry (5). Yielding and Plasticity. P. Feltham. (Iron and Coal Trades Review, 1950, vol. 161, July 28, pp. 183–186). The author examines the nature of the most important fundamental yield criteria and the technical aspects of the problem of plasticity, and discusses their importance in the design of metal working equipment. Yield criteria in polycrystalline metals and the yielding of single crystals are described, and stress and strain in the plastic region are considered. Brief reference is made to wire drawing and deep drawing of steel as typical examples of metal working.—G. F.

The Effect of the Free Surface on the Hindering of Deformation in Polycrystalline Material. F. Vitovec and A. Slibar. (Schweizer Archiv, 1950, vol. 16, Mar., pp. 76–80). In polycrystalline materials, the deformation of each crystallite is hindered by the influence of its neighbouring crystallites. The effect on any crystallite of those lying in a spherical layer surrounding it depends on the radius of the spherical layer. As the radius increases, the effect decreases slowly at first and then rapidly approaches zero. The total hindering effect on the deformation of any crystallite can thus be estimated by summation of the effects of a finite number of these successive spherical layers. For crystallites near a free surface, a part of this spherical field of influence is missing, and crystallites actually on the surface are affected only by a hemispherical field. Plastic deformation will thus occur first on the surface and be propagated from the surface towards the inside of the

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material. From these theoretical considerations, an expression is derived for the hindering of deformation as a function of the distance from the free surface, with parameters expressing the mode of crystallization, the grain size and shape, and the effect of grain boundaries.—H. R. M.

The Field of Influence of Strain Hardening. A. Slibar and F. Vitovec. (Schweizer Archiv, 1950, vol. 16, Mar., pp. 80–84). The increase in resistance to deformation of a polycrystalline material as the deformation progresses is made up of two parts. The first part is the strengthening due to slip and is given by the mean stress-strain curve for single crystals, while the second is due to the hindering of flow resulting from the mutual effect of differently orientated neighbouring crystals. The latter depends on the mode of crystallization; for example, it is constant in face-centred cubic metals but increases rapidly with increasing deformation in hexagonal metals. An expression for this hindering of flow is derived, which can be evaluated by a finite summation, since tests show that the field of mutual influence of crystallites only extends for about 10 to 20 layers.—H. R. M.

Lateral Contraction beyond the Elastic Limit. F. Vitovec. (Schweizer Archiv, 1950, vol. 16, Mar., pp. 85–87). On the assumption that the volume of the material remains constant during plastic deformation, the coefficient of lateral contraction (1/Poisson's ratio) can be calculated. If the change of length is measured as a proportion of the original length, the coefficient of lateral contraction for uniaxial tension increases, while for uniaxial compression it decreases as the change of length is increased. The smaller the deformation, the nearer does this coefficient approach the value 2 for both tension and compression. If extension and contraction are measured logarithmically, however, the coefficient of lateral contraction is equal to 2, regardless of the amount of deformation.

H. R. M.

An Industrial Method for the Determination of Residual Stresses. W. Soete and R. Vancrombrugge. (Proceedings of the Society for Experimental Stress Analysis, 1950, vol. 8, No. 1, pp. 17–28).) Mathar's classical method of drilling a small hole in the stressed member, and measuring the elastic spring back, has been made more accurate by using electrical resistance strain gauges instead of dial extensometers. The authors outline the mathematical theory of the stress problem, and illustrate the method by giving the results of experimental determinations of residual stresses in a butt weld and in a fillet weld. In a written discussion, K. P. Milbradt outlines the 'Ring' method which, it is claimed, gives twice the response of the hole method.—P. M. C.

The Influence of Bolt Tension and Eccentric Tensile Loads on the Behavior of a Bolted Joint. T. J. Dolan and J. H. McClow. (Proceedings of the Society for Experimental Stress Analysis, 1950, vol. 8, No. 1, pp. 29–43). The paper deals with the strains developed in those types of bolted joints that are loaded with forces applied perpendicular to the surfaces of contact of the two members, (no shearing forces act on the plane of contact or on the bolts). By making certain simplifying assumptions, the authors derive theoretical expressions for (*a*) the strains developed in the bolt and members by tightening loads, and (*b*) the external loads required to initiate separation at the parting line. Details of an experimental investigation, in which these strain gauges were used to examine such a joint loaded in tension, show that the theoretical expressions give results which approximate closely those obtained by experiment.—P. M. C.

The Method of Oblique Incidence in Photoelasticity. D. C. Drucker. (Proceedings of the Society for Experimental Stress Analysis, 1950, vol. 8, No. 1, pp. 51–66). Single oblique incidence, and double oblique incidence techniques have previously been proposed respectively by the author and by Norris and Voss. An alternative double oblique incidence procedure is now presented in which retardation values alone determine the magnitudes of the principal stress differences. The application of these techniques to two-dimensional models, and in certain cases to principal slices cut from 'frozen' models is discussed. The mathematical derivation of the formulæ for each method is given, and numerical examples are worked out which indicate that the last-named method is the most accurate.—P. M. C.

Analysis of Amplitude Modulation Systems and Design of Tuned Amplifiers for Use with Strain Gages and Similar Instrumentation. W. R. Mehaffey and A. J. Hoehn. (Proceedings of the Society for Experimental Stress Analysis, 1950, vol. 8, No. 1, pp. 79–92). This paper includes the derivation of the general equations used in strain gauge bridges and a modified bridge analysis. The modified analysis is used to evaluate the carrier terms and side-band terms in an amplitude modulation system. This analysis is extended to cover the case of harmonics in the bridge supply voltage. The results of the analysis show the presence of both carrier and side-band terms. The side-band terms consist of the useful term and the distortion terms, the latter being shown to be negligibly small compared with the former. Initial resistance unbalance of the bridge circuit results in variation of the carrier term without affecting the side bands. The presence of harmonics in the bridge supply voltage results in several harmonically related carrier frequencies, each with its associated side bands. All of these terms are quite small and can be eliminated completely by the use of a tuned amplifier. A band-pass, audio-frequency amplifier using the tagger tuned principle is described.—P. M. C.

Characteristics of Electric Strain Gages at Low Temperatures. E. E. Day and A. H. Sevand. (Proceedings of the Society for Experimental Stress Analysis, 1950, vol. 8, No. 1, pp. 133–142). The design of a simple low-temperature box is presented, along with the techniques and methods used for determining the effects of low temperatures on the strain sensitivity factor of ordinary commercial wire strain gauges. The gauges were cemented on to a beam which was subjected to a constant bending moment, and measurements were made of beam deflection, load applied, and gauge resistance at temperatures ranging from −290° F. to + 25° F. Strain sensitivity factors at the lowest temperatures considered, were approximately 6 to 8% higher than at room temperature, whilst at −200° F. the change was only about 3%.—P. M. C.

Tests and Theory of Elastic Stresses in Curved Beams Having I- and T-Sections. D. C. Broughton, M. E. Clark, and H. T. Corten. (Proceedings of the Society for Experimental Stress Analysis, 1950, vol. 8, No. 1, pp. 143–155). Experiments carried out on sharply curved beams having flanged-type **I**- and **T**-cross-sections, show that the actual elastic stress existing in the inner fibres of the inner flange may be up to 30% greater than that computed by the Winkler-Bach formula. The authors have analysed the problem theoretically, allowing for the additional bending in the flanges, and they deduce a corrected Winkler-Bach formula which gives computed results which agree well with experiment.—P. M. C.

A Method for the Determination of Initial Stresses. C. Riparbelli. (Proceedings of the Society for Experimental Stress Analysis, 1950, vol. 8, No. 1, pp. 173–196). The method consists of introducing a circular discontinuity in the surface of a body possessing residual stress, and measuring by means of electrical resistance strain gauges the resulting stresses occurring in the vicinity of the hole. The several recognized arrangements of gauges are illustrated, and the analysis of two-dimensional stress and strain in the vicinity of a hole is outlined. An account is then given of an experimental calibration of a number of systems of SR-4 gauges, using $\frac{1}{8}$ in. × 2·9 in. square duralumin plates uniformly loaded in compression, and having various diameter holes at their centres.—P. M. C.

The Design of a High-Speed Polariscope. J. J. Baruch. (Proceedings of the Society for Experimental Stress Analysis, 1950, vol. 8, No. 1, pp. 197–204). The author has designed a small portable polariscope which has the following desirable features: it has a 7-in. working field; it is only 36 in. long; it employs diffuse light and includes no lenses (apart from the camera lens); the light source is a type 1532-A Stroboflash enabling the instrument to be used for both static and dynamic applications; and it can be used in a normally lit room. Photo-elastic stress patterns are shown to illustrate the excellent performance of this instrument compared with that of a standard one, and some examples of dynamic applications are shown.—P. M. C.

Investigations on Standards for the Weldability of Steels. (Revue de la Soudure, 1950, vol. 6, No. 2, pp. 59–71). This paper gives the results of three separate investigations carried out under the direction of a combined Dutch and Belgian committee on the weldability of steels. The primary object of the investigations was to find an adequate and practical method of testing welds for brittle fracture. The first series

of investigations made use of resilience testing at low temperatures. The type of test, refrigerating apparatus, testing technique, and results are discussed. The second series deals with the types of specimen most suitable for resilience testing. Consideration is given to the materials and the relation between resilience and temperature. A full description is given of the results obtained. Finally, the third investigation deals with the problems arising out of the notching of test pieces. The Schnadt method is described and discussed. The materials, the methods of investigation, and the variability of notches as tools wear blunt are examined as well as the measure of hardness and the influence of notching technique on resilience.—M. D. J. B.

Defectoscope for Determination of the Wear of Steel Ropes for Mine Hoists. A. L. Vinogradov. (Gornij Zhurnal, 1949, June, p. 27). [In Russian]. The defectoscope described is an electrical instrument with the scale calibrated to give direct readings of the wear in percent of the total cross-section of the rope. The speed of examination does not exceed 0·3 m./sec.—E. G.

Sherardized Bolts. H. H. Symonds. (Metal Industry, 1950, vol. 26, May 26, pp. 423–424). The author outlines briefly an investigation into the cause of fracture of several sherardized bolts. Plain and notched bend tests, and micro-examination indicated that the failures were not due to the sherardizing operation. The cracks which led to ultimate fracture during tightening up were initiated by the condition of the rod material, which exhibited intergranular oxide and carbide.—P. M. C.

Causes of Tool Failures. I—Mechanical Factors. II—Improper Heat Treatment. J. Y. Riedel. (Metal Progress, 1950, vol. 58, Aug., pp. 171–175; Sept., pp. 340–344). Failures are considered as due to faulty design, steel defects, surface stresses caused during grinding, stresses after repeated heating, and rapid wear; of these, errors in heat-treatment account for about 80% of the total failures. Typical cracks are illustrated, and methods of crack detection discussed.

E. T. L.

Determining the Causes of Rupture of Parts in Service. A. Fotiadi. (Métallurgie, 1950, vol. 82, June, pp. 485–501; July, pp. 573–583). A systematic analysis is made of service fractures, based on practical first-hand data mainly from the field of aircraft engines. Seventeen diagrams illustrate the parts fractured in service or testing, due to defects in design. After describing the fractures, the peculiarities giving rise to the failures are discussed. Conditions of testing the engines on special benches are more severe than service conditions (a 150-hr. test corresponds to 500 hr. in the air). The study is divided into three parts: (1) A description of the actual fractures (including coil springs, pistons, connecting rods and crankshafts, and propeller shafts); (2) a survey of various types of fracture; and (3) the tensile properties of steels and light alloys. The fracture of a part is a good guide to the direction of the stresses.—R. S.

Fatigue Properties of Helical Springs for I.C. Engine Valve Springs and Other Duties. B. M. Pearson. (Wire Industry, 1950, vol. 17, Dec., pp. 987–989). This is a résumé of research conducted by Pomp and Hempel. The investigations were concerned with the effect of composition, processing, heat-treatment, and temperature of operation on the fatigue limit of both alloyed and unalloyed springs. In general, it was found that there was no difference in the endurance of springs manufactured from oil-quenched wire and of springs oil-quenched after coiling; there was also little difference between alloyed and unalloyed steels. The most important factor was surface quality, the rolling and drawing procedure being of little significance. Shot-peening raised the fatigue limit not only at room temperature but also at 250° C. The surface hardened springs fractured most frequently in coils two and five, the fractures were distributed irregularly in the case of the non-surface-hardened springs. In both quench and surface-hardened springs the fatigue fracture started most frequently from a point on the inner surface of the coil; the exact reverse was true of shot-peened springs. The permanent deformation of springs subjected to alternating loads depended to a marked degree on the testing temperature, and was also influenced by the degree and duration of loading. This permanent set was greater in the case of springs manufactured from quench-hardened wire and less for springs quenched after coiling.—J. G. W.

On the Problem of the Formation of Fatigue Microcracks. G. V. Karpenko. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 74, No. 1, pp. 95–98). The formation of 'slips' followed by fatigue microcracks takes place preferably in regions with a minimum of surface energy: the manner in which this is affected by the smoothness of the metal surface and the presence of active media is explained.—R. A. R.

The Fatigue Strength of Rope Wire and Wire Ropes. H. Donandt. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Sept.–Oct., pp. 283–292). The rules at present used for the design of wire ropes for conveying equipment are based on the relation of the maximum service stress to the tensile strength of the material. The fatigue strength diagram of the wire shows that this concept can lead to erroneous conclusions. The problem exists therefore to determine completely those characteristics of wires which are necessary to design a wire rope on the basis of its fatigue strength and which are not yet sufficiently well known. Research must continue on wire ropes, too, since all alternating and tensile stresses have to be taken into consideration. In this way it will be possible to separate the primary stresses from those which result from the movement of the ropes around pulleys, drums, etc. It will thus be possible to recognize and allow for the individual factors which affect the mechanical strength of wire ropes, and so facilitate development and standardization for use in mines and other conveying systems.—J. P.

Evaluation of Fatigue Tests in the Testing of Materials. W. Späth. (Metall, 1950, vol. 4, Sept., pp. 374–377). The author suggests that instead of the familiar S–N curves one should plot stress semi-amplitude against the reciprocal of the number of reversals which he terms the 'rate of destruction' by fatigue. Whereas the S–N curve approaches the fatigue limit asymptotically, in the author's diagram the fatigue limit is read off at the intersection of the endurance curve with the ordinate axis, because the fatigue limit is the stress semi-amplitude for which the rate of destruction is zero. He illustrates his method with the aid of results of tests on one steel, four cable-sheathing lead alloys, and four aluminium alloys. By a suitable choice of the number of reversals for which the rate of destruction is taken as unity, these 'reciprocal' curves are made nearly linear so that extrapolation to the fatigue limit is unequivocal. In the case of the aluminium alloys the conventional S–N curves plotted on a log basis continued to drop even after 10^9 reversals. It appears from the author's diagram that a very low fatigue limit exists after about 10^{15} reversals.—J. G. W.

Pulsating Pressure Test Plant of the British Welding Research Association. (Engineer, 1950, vol. 190, Oct. 13, pp. 370–371). This article describes a new pulsating-pressure plant recently installed at the British Welding Research Association at Abington Hall near Cambridge. This plant, the first of its kind in the country, is to be used for the fatigue testing of pressure vessels. Pressures up to 6000 lb./sq. in. are obtainable and pressure cycles can be repeated up to 100 times/min. A description of the test plant and pulsating-pressure plant controls is given. The plant was designed for the association by Werner and Pfleiderer of Stuttgart and it is anticipated that information obtained from tests with the new plant will make it possible to establish the relationship between material properties, service stress, and the life expectation of pressure vessels in service.—M. D. J. B.

Gear-Tooth Stresses at High Speed. W. A. Tuplin. (Proceedings of the Institution of Mechanical Engineers, 1950, vol. 163, pp. 162–175). *See* Journ. I. and S.I., 1951, vol. 167, Jan., p. 101.

Fatigue Data Summary Report No. 1. M. E. Annich. (American Foundrymen's Society, May, 1950, Preprint No. 50-51). Fatigue data received by the Timestudy and Methods Committee of the American Foundrymen's Society from various foundries in response to a questionnaire are reported to be very gratifying. The replies are summarized in tabular form.—E. J. D. S.

The Behaviour of St 37 Steel in Fatigue above the Endurance Limit. E. Gerold and K. Trachte. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, May–June, pp. 175–179). The relationship has been investigated between the practically deformationless fracture which occurs with small pulsating tensile overloading in the fatigue range and the fracture with marked necking which occurs in the tensile test. As the stress is increased a progressive transition from a fatigue to the usual tensile rupture has been found in the

appearance of the fracture as well as in the uniform extension and necking. The ascending branch of the Wöhler line rises less steeply with increasing stress and decreasing endurance and attains the value given by the tensile test. No such relationship could be established in the case of the alternating bend test. The rising branch of the Wöhler line, on a semi-logarithmic diagram, is linear up to the highest stress investigated (endurance some 1000 cycles) which is approximately 45% higher than the usual bending strength. While in tensile and pulsating tensile stressing the deformations increase with increasing time, they are cancelled out in alternating bend or push-pull tests. Herein lies the reason for the different shape of the Wöhler lines obtained by the two methods of stressing.—J. P.

The Influence of Alternating and of Sudden Overloading on the Endurance of Steel under Alternating Bend Stress. A. Drozd, E. Gerold, and E. H. Schulz. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, May–June, pp. 181–189). In alternating bend tests with St37 and St52 steels the order in which variations of loading are applied has a great influence on endurance. The endurance is raised if a short preliminary period at a lower stress has been given, but is lowered if the preliminary period is at a higher stress. Longer preliminary periods are unfavourable whether the stress is higher or lower than the final. This behaviour contradicts previous assumptions that the damage due to individual overloadings is simply additive and is explained on the basis of the inner structure of the metal. The favourable influence of a short overloading on the endurance at a subsequent higher stress is independent of whether the stress range is above or below the yield point. It is obviously a question of a work-hardening such as that known as 'training' which occurs with alternating stressing below the fatigue limit and which induces an increase in fatigue strength. The interposition of a period of lower overstressing between two periods of alternating stress has a favourable influence on the endurance, providing that the higher initial stress has not acted for a sufficient length of time to produce damage. An interposed period of higher stress has always an unfavourable effect. A sequence of three periods of increasing stress increases endurance whereas a sequence of decreasing stress is unfavourable. The number of sudden overloadings which an alternately stressed specimen can withstand before fracture is greater the faster the overloadings succeed one another. Similarly, the endurance of an alternately stressed specimen, subjected to a given number of blows, will be much decreased if the blows occur in slow succession, compared with that observed when all the blows occur within a short space of time. It was shown by damping measurements that a slow succession of sudden blows damaged the material more than a faster succession. A material 'trained' by alternate stressing also shows an increased resistance to sudden overloading.—J. P.

Rapid Methods for the Determination of Fatigue Strength. E. Gerold and A. Karius. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, May–June, pp. 191–195). The various proposed methods for calculating fatigue strength from other properties such as tensile strength, are reviewed. The new method consists of applying a succession of 50,000 stress reversals of 2, 4, 6, etc., kg./sq. cm. and measuring the damping or resonance frequency by the Förster method after each set of reversals. The two properties mentioned remain essentially constant up to a certain value of stress, which corresponds closely with the fatigue strength as determined by the Wöhler method, and then show a sudden increase or decrease, respectively. The method is applicable to unalloyed steels of less than 0·6% C; it is not reliable for heat-treatable chromium steels, for some non-ferrous alloys, or for notched specimens.—J. P.

Fatigue Strength of Coil Springs Prepared by Different Methods. A. Pomp and M. Hempel. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, July–Aug., pp. 243–262). Experiments have been carried out to determine the fatigue strength of springs made from three alloy and one unalloyed steel. The results show wide scatter so that the lower limiting curve is taken as the Wöhler line to be on the safe side. The mean fatigue limits as determined on two different machines were in agreement within experimental error. The wires had been ground before making into springs and it was found that the number of surface defects had no effect on fatigue strength; moreover, there was no superiority of alloy steel over unalloyed and it appeared to be immaterial whether the wire was heat-treated before or after making into springs. Shot-peening of the springs produced a mean increase in the fatigue strength of the order of 32–36%. The marked scatter in the results indicated that peening conditions have a pronounced effect. The change of the load-extension curves of alternately stressed springs is small compared with that of the springs as prepared. The permanent set of shot-peened and untreated springs is of approximately the same nature and extent, but the permanent set of heat-treated springs is less than that of springs made from heat-treated wire. Some observations are made as to the nature and frequency of fracture.—J. P.

Fatigue Limit of Coil Springs at Elevated Temperatures. A. Pomp and M. Hempel. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, July–Aug., pp. 263–272). The fatigue strength of coil springs of different materials and different surface finish has been determined at 20° and 250° C. The methods and experimental equipment are described. At both temperatures the values of fatigue strength show wide scatter. The fatigue limit of non-peened springs made from heat-treated alloy wires is the same at 20° as at 250° C., springs of unalloyed steel show a slight decrease at 250° C. At the higher temperature the fatigue limit of unpeened heat-treated springs is slightly higher than at the low temperature. Shot-peening increases the fatigue limit of both types of spring, but at 250° C. peening has no effect on the endurance limit of springs made from heat-treated wire, whereas peening induces an additional increase in the limit at 250° C. of the heat-treated springs. Composition appears to have no effect on the fatigue limit at 20° or 250° C.; no particular steel could therefore be recommended for spring making. The permanent set of springs is independent of surface finish at both temperatures. The fractures which occur at 250° C. are similar to those at 20° C.—J. P.

The Effect of Multiple Stress-Raisers, Attenuating and Intensifying Notches. A. Thum and O. Svenson. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, Apr. 1, pp. 225–230). The effect of single stress raisers, such as holes, shoulders, slots, and keyways, has been thoroughly investigated, but the more complex effects of multiple stress raisers are less well understood. The authors distinguish four kinds of multiple stress raisers: Those in series, that is, in line with the principal line of action of the applied forces; those in parallel, that is, at right angles to the forces; stress raiser fields, *e.g.*, multiple rows of holes in a plate, and 'penetrating' stress raisers, *e.g.*, two radial holes at right angles to each other in a rod in axial tension. The additional stress raisers may either attenuate or intensify the stress concentration caused by a single stress raiser. The first class of multiple stress raisers is chiefly of the attenuating type, the other three usually aggravate the stress concentration. The effect of stress raisers may be measured in terms of three quantities: (1) The basic form factor which is the ratio of the average stress in the reduced cross-section to the stress in the unreduced cross-section of the part. (2) The stress concentration factor, that is the ratio of the maximum stress to the stress in the unreduced section; and (3) the stress gradient at the point of maximum stress. The authors analyse some typical examples in each class, and by evaluating these characteristic numbers demonstrate, for instance, that several notches in series alternate the stress concentration produced by a single notch, and that in a beam with a central point load a hole under the load will reduce the maximum stress if its diameter is less than half the depth of the beam, and increase it if it is larger. Finally, they develop a method for calculating the stress concentration produced by stress raisers of the 'penetrating' type. Twenty-one references are listed.—J. G. W.

Problem of Decarburization in Railroad Materials. R. McBrian. (Metal Progress, 1950, vol. 58, July, pp. 51–54). Rails suffer surface decarburization during manufacture, lowering the fatigue resistance. Furthermore, the decarburization is not uniform. This effect is not sufficiently realized by rail designers.—E. T. L.

The Correlation between Different Hardness Numbers for Grey Cast Iron. J. Wozniacki. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 162–170). [In English]. The author suggests classifying metals on the basis of Young's modulus, the strain-hardening

capacity, and the hardness numbers obtained before creating empirical formulæ for conversion from one hardness scale to another. Young's modulus affects conversion calculations, especially at high hardness values; strain-hardening capacity affects the conversion in the case of softer metals. These factors are discussed in detail and illustrated by tests by Brinell and the Alpha microhardness tester on pearlitic bar sections. Microstructures of the specimens are illustrated. Correlations are indicated by the tables, and graphs are plotted.—R. S.

Uncertainties in Influence of Alloys on Hardenability. M. A. Grossmann. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 111–129). The concept of hardenability is discussed together with the difficulties encountered in expressing it quantitatively. The Jominy test is briefly mentioned and detailed consideration given to the 'critical diameter' method of hardenability measurement. The effects of alloying elements on hardenability are shown graphically. Unfortunately these results are only applicable to steels of low hardenability.—D. H.

Hardenability of Steels. V. G. Paranjpe and J. H. McMahon. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 85–110). The paper reviews the gradual development of the quantitative aspects of hardenability over the past 30 years. The hardenability concept is discussed briefly. The Grossmann method of determining hardenability, or 'quenched rounds test' is described and its main disadvantages are given. The Jominy end-quench test developed to eliminate the practical difficulties associated with the Grossman method is considered and its failure to deal satisfactorily with shallow-hardening steels noted. The two main factors affecting hardenability are chemical composition and grain size. A method is given whereby hardenability can be calculated from these two factors. The selection of the steel for a specific purpose can be made by a method based on hardenability, and examples of its use are given. There are 53 references.—D. H.

Construction and Use of a New Type of Hardness Tester. L. Tschirf. (Österreichischen Maschinenmarkt und Elektrowirtschaft, 1950, vol. 5, Oct. 15, pp. 400–405). The 'Emcotest' hardness-testing unit was developed to fill the need for a cheap but accurate instrument which could be used as a portable instrument in any position. Although designed on the Rockwell principle, it can be used for Brinell, Vickers, or similar tests if a microscope is available. The testing head, which can be used in a stand, in a portable **C**-clamp or in any special fitting, contains a pair of concentric springs, for applying the minor and major loads (*e.g.*, 10 kg. and 150 kg. for the Rockwell C test), and the dial gauge for measuring depth of impression. The indenting tools and the sealed boxes containing the springs are interchangeable so that the type of test can readily be changed. The minor load is applied by bringing the indenting tool into contact with the material and the major load by movement of a hand lever. On account of the small masses involved and the direct load application and measurement of depth, without using levers, the instrument is practically insensitive to vibration or too rapid load application. Tests have shown its accuracy to be well within the limits of the DIN specification for Rockwell tests.—H. R. M.

The Hardness of Cast Iron in Relation to Its Other Mechanical Properties. J. Gélain. (Fonderie, 1949, Dec., pp. 1873–1875). The relationship between the Brinell hardness and the tensile strength of annealed carbon steels (up to 1% carbon) is discussed. The part played by structure in the degree of this relationship is explained and the importance of care in assessing other mechanical properties from the hardness values of any given cast iron is emphasized.—R. S.

Portable Indentation Hardness Tester. (Engineering, 1950, vol. 170, Dec. 1, p. 437). This article describes a portable diamond indentation hardness testing instrument, which, it is claimed, is sufficiently robust for use in the workshop whilst retaining the accuracy of a laboratory instrument. The hardness tester is manufactured by the Cabul Tool Co., Ltd., London. It is readily portable and weighs only 22 lb. complete with case, battery, and lamp. Used in conjunction with British Standard 427-1931 conversion tables, the instrument gives diamond-pyramid hardness numbers.—M. D. J. B.

Standard Steels and H-Band Steels. D. H. Ruhnke, E. T. Walton, and P. R. Wray. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 90–102). The method of specifying constructional alloy steels by means of hardenability bands, or minimum and maximum hardenability limits, is discussed and compared with the standard chemical composition method of specification. The closer control of hardenability gives a product that is more satisfactory in heat-treatment and results in fewer rejections. The derivation of hardenability bands (H-bands) is described. G. F.

Influence of Microstructure on the Mechanical Properties of Heat-Treated Steels. (Boletin Minero e Industrial, 1950, vol. 29, Aug.–Sept., pp. 437–439). [In Spanish]. Martempering gives the maximum elongation and impact strength for a given maximum stress. It is easy to determine the percentage of martensite obtained after hardening if the carbon content is known, since, for a given carbon content, the hardness obtained after quenching is a function of the percentage of martensite. Optimum combinations of mechanical properties are discussed in relation to 100% and 50% martensite.—R. S.

Hot Hardness of Hard-Facing Alloys. S. Avery. (Welding Journal, 1950, vol. 29, July, pp. 552–578). Hot hardness, which is of interest chiefly because of the implied hot wear resistance, has been surveyed at 600, 800, 1000, and 1200° F. for a number of hard-facing alloys, using a Rockwell diamond indenter technique. Some indication of creep resistance, which becomes important as a variable at the higher temperatures, is obtained by incorporating a time factor in the test. Arc welds, gas welds, and castings of wear-resistant alloys are included in the survey, which covers most of the types in the current American Welding Society classification of hard-surfacing alloys. Elements such as chromium, tungsten, and molybdenum, which cause marked secondary hardening, contribute to good hardness retention up through 1000° F. At 1200° F. solid solution hot strength and primary carbides appear of major importance. There are 39 references.—U. E.

Temper Brittleness and Hardness. G. Riedrich. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, May–June, pp. 165–173). Hardness measurements on three different low-alloy steels make it seem probable that the tendency to temper brittleness depends on a precipitation process in the α-iron. Microscopical studies indicate that this is a carbide precipitation; the reduced toughness in a temper embrittled state is attributed to partial precipitation at the surface of the grains and thus a reduced grain adhesion. The result of this is that the brittle fracture is partly intercrystalline. In the annealed state, precipitation causes no reduction of toughness since there is no migration of the precipitated carbides towards the grain boundaries, but no reason for this can be given. Carbide precipitation in α-iron causes temper brittleness only if the carbides migrate to the crystal surfaces.—J. P.

X-Ray Aspects of the Temper Brittleness of Cr–Mn–Va Steel. F. Erdmann-Jesnitzer and F. Günther. (Die Technik, 1950, vol. 5, Apr., pp. 203–207). Cr–Mn–Va steel suffers from pronounced temper brittleness in the region of 600–650° C., the cause of which has not hitherto been clearly established. The authors carried out an X-ray examination of three low-carbon, low-alloy constructional steels, of which one (0·25% C, 0·5% Cr, 1·08% Mn, 0·1% Va, 0·41% Si, 0·023%P) exhibited this temper brittleness. Back reflection photographs showed diffused lines for specimens of this steel treated below 600° C., and contained doublets in the case of specimens treated in the temper-brittle range. The structures associated with these observations were fully reversible and suggested that a precipitation of impurities takes place on grain boundaries during a transformation from a cubic β-martensite type of structure to that of the body-centred ferrite.—J. G. W.

Midcentury Review of Progress in S.A.E.–A.I.S.I. Alloy Steels. J. Mitchell. (Metal Progress, 1950, vol. 58, Oct., pp. 491–498, 562). This is a historical account of research and application of constructional alloy steels, particularly in automobile construction, in America. It is pointed out that in America composition tolerances are closer, and the range of alloys used is smaller than in other countries, because of standardization, and it is claimed that Americans are further advanced in heat-treating techniques. The author prophesies a slight increase in the proportion of alloy steels, compared with plain carbon steels, used in the next few years.—E. T. L.

An Investigation into the Causes of Brittleness in Mild Steels. J. G. de Lattre. (Sheet Metal Industries, 1950, vol. 27, July, pp. 613–618, 628). The author outlines an investigation carried out on 20 samples of basic-Bessemer steel which displayed a high degree of brittleness. The results of chemical analysis and tensile tests indicated that the ductility, as measured by the elongation, increased with increasing aggregates of the reducing elements carbon and manganese. The author attributes this to the better deoxidation of the steel when the carbon plus manganese content is high. Micrographical examination showed that all the samples had exceptional structures, the main defect being separations at crystal boundaries, which the author attributed to intercrystalline occlusions of gas. This condition would, on quenching, give rise to the brittle state. Efficient de-oxidation, and elimination of the gaseous elements oxygen, nitrogen, and hydrogen, should ensure steel free from brittleness.

P. M. C.

Low-Cost Inspection Method Ends Metal Surface Flaws. (Steel, 1950, vol. 127, July 24, pp. 68–70). This article describes the Dy-Chek method of crack detection developed by the Turbodyne Corp., California. A non-toxic, non-corrosive red dye of high capillary action is used in conjunction with a special developer. The facts that the surface need not be smooth and the equipment is entirely portable are assets.

A. M. F.

The Phenomenon of Wear—A Practical Device for Testing Abrasion. N. G. Neuweiler. (Microtecnic, 1950, vol. 4, Sept.–Oct., pp. 283–287). In the present publication, several important questions in connection with friction and abrasion are dealt with, and a description is given of an abrasion-testing device much used in the United States but practically unknown in Switzerland.—E. T. T.

The Deformation of Copper and Iron Crystals by Unidirectional Abrasion. D. M. Evans, D. N. Layton, and H. Wilman. (Proceedings of the Royal Society, Series A, 1951, vol. 205, Jan. 22, pp. 17–30). With the aim of testing further Wilman's conclusion that a new deformation process, rotating slip, occurs prominently when crystal surfaces are abraded unidirectionally, a face of a copper crystal was smoothed by electropolishing, abraded, and examined after various stages of etching. The immediate surface regions were heavily disorientated, but those slightly below the surface had mostly become rotated by about 35°. In iron, also, large rotation of parts of the crystal surface occurred when crystals were abraded parallel to either $\{100\}$, $\{110\}$, or $\{111\}$ planes which were normal or steeply inclined to the surface. The deformation caused by abrasion is analogous to the development of 'deformation bands.'—R. A. R.

The Telerecording of Thickness, Pressure, Flow and Other Physical Quantities Using a Simple Electromagnetic Circuit. W. J. Clark. (Transactions of the Society of Instrument Technology, 1950, vol. 2, Mar., pp. 18–45). This report describes a simple method of recording changes in induction in an electromagnetic circuit, and the adaptation of this method over a number of years to the design of a variety of industrial measuring instruments. Applications include measurements of thickness of non-ferromagnetic metals, thickness of non-ferromagnetic coverings on a ferromagnetic backing, specific resistance, change in length, pressure, and pressure difference without the use of manometric liquids, wind velocity with linear velocity scale, gas density, thermal conductivity compensated for pressure effect at low pressures, ferromagnetic properties, flow (based on telerecording the movement of a rotameter float), pressure difference (based on change in level of a manometric fluid), liquid level (using no auxiliary fluid), and liquid density. The treatment of this subject is mainly historical and illustrates how a certain electromagnetic principle first came to be applied and how it was found possible to utilize the same principle with improvements in design to solve a succession of industrial measurement problems over a period of 11 years.—E. T. T.

The Hardening of Iron–Gold Alloys. W. Köster and E. Braun. (Zeitschrift für Metallkunde, 1950, vol. 41, Aug., pp. 238–240). An alloy of pure iron with 10% gold, obtained by quenching from 1200° C., was tempered at temperatures from 400° to 700° C., and the resulting hardness and coercive force were measured at room temperature. The coercive force was also measured at the tempering temperature by Förster's magnetic method. From the time taken to reach maximum coercive force the activation energy of solution of gold in iron can be found, using the Arrhenius equation; it was about 72,000 cal./mol., compared with 33,000 for copper and 18,000 for carbon and nitrogen in iron.—N. McK.

Are You Overlooking Ferromagnetic Analysis? J. K. Stanley. (Steel, 1950, vol. 127, Oct., pp. 88–92). A review is given of the uses to which magnetic analysis can be put in interpreting metallurgical phenomena. These include the physical tests for inhomogeneities, identity, coating thicknesses, stress analysis, and fatigue and endurance. Structural studies such as the determination of equilibrium diagrams, retained austenite, the occurrence of ferrite in austenite, the decomposition of austenite, and the precipitation of beryllium from a nickel alloy have also been carried out.—A. M. F.

Modern Permanent Magnets for Electrical Instruments. D. A. Oliver and D. Hadfield. (Transactions of the Society of Instrument Technology, 1950, vol. 2, Mar., pp. 46–58). Many applications of moving-coil permanent magnet instrument are mentioned and some consideration is given to the relevant factors in magnet design. The principal requirements in magnet design are that the magnet must have a cross-sectional area sufficient to provide both the leakage flux and the required flux across the air gap, and that its length must be sufficient to provide the magnetomotive force to overcome the reluctance of the complete magnetic circuit. Although assembly of a magnet in an instrument is equivalent to a measure of artificial ageing, instrument manufacturers are recommended to magnetize and age their magnets after assembly, as the ageing which results from assembly is usually excessive, and therefore wasteful, and not always under precise control. Permanent magnet materials are classed into magnet steels (either as carbon, tungsten, chromium, or cobalt steels), and magnet alloys. The permanent magnet alloys are inherently more stable magnetically and metallurgically, and do not require the special precautions and treatments which were necessary to obtain stability with the steels. Composite magnets of sintered Alnico and sintered iron are also possible by the powder-metallurgy technique.

E. T. T.

Experimental Study of Structural Reorganizations Caused by Thermal Treatment in Binary and Complex Ferronickels. E. Josso. (Revue de Métallurgie, 1950, vol. 47, Oct., pp. 769–778). The rôle of temperature, time, and speed of cooling, and the effect of thermal treatment on the magnetic properties of complex ferronickels with high initial permeability were studied by dilatometric and thermomagnetic methods. The volume change for the order–disorder reaction in binary ferronickels is a maximum for the composition corresponding to Ni_3Fe. Order can exist in quaternary alloys such as Ni 77–78%, Cu 5%, Mo 4%, with the remainder iron. It is shown that the mode and temperature of the magnetic transformation is dependent on the degree of order. Order is established more readily by quenching and reheating than by slow cooling. The temperature at which disorder returns is higher the more perfect the prevailing order up to a maximum of 550° C.—A. G.

New Developments in the Non-Destructive Testing of Materials by Electrical and Magnetic Methods. W. Jellinghaus. (Iron and Steel Institute, 1951, Translation Series, No. 414). This is an English translation of a paper which appeared in Stahl und Eisen, 1950, vol. 70, June 22, pp. 552–560 (*see* Journ. I. and S.I., 1951, vol. 167, Feb., p. 231).

Magnetic Properties of Malleable Cast Iron. F. Danis. (Fonderie, 1950, Nov., p. 2267). Normal malleable cast iron has a completely ferritic matrix interspersed with nodules of graphite. Magnetically, it behaves like the silicon steels. Black-heart malleable cast iron has better magnetic properties than those of white-heart malleable. The latter is often incompletely decarburized and contains regions of pearlite; its silicon content is lower than that of black-heart. A good black-heart malleable cast iron has superior magnetic properties to those of a killed soft steel, up to a field of 9000 to 10,000 gauss.—R. S.

Magnetic Properties of Cast Steel. V. Zednik. (Schweizer Archiv, 1950, vol. 16, Mar., pp. 65–75). The strength of cast steel can only be increased by increasing the carbon content or adding other elements, but both these methods generally have the result of making the magnetic properties poorer, although nickel has a slightly beneficial effect. Statistical examination of measurements on specially deoxidized steels shows that the change of magnetic induction is not directly proportional to

the quantities of alloying elements added, particularly for carbide-forming elements like chromium and manganese. The amounts of the added elements relative to the carbon content have a great influence; so also does the thermal treatment of the steel, which affects their distribution between ferrite and carbide. Small, evenly distributed inclusions have a significantly smaller effect on magnetic induction than dissolved impurities in the ferrite, so that effective deoxidation is important. Using an excess of aluminium for deoxidizing, although it reduces the plasticity of the steel, has no deleterious effect on its magnetic induction. By careful choice of chemical composition and complete deoxidation, it is possible to produce cast steels of higher strength which still fulfil the usual specifications for magnetic properties.—H. R. M.

New Developments in the Field of Magnetic Materials. H. Fahlenbrach. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, July 21, pp. 565–570). Notable developments have recently taken place in the field of magnetic materials. As a result of the introduction of permanent magnets sintered from extremely fine iron powder (grain size 1μ), of machinable iron–cobalt–vanadium alloys, of stainless steels, and of great strides in the development of the powder metallurgy of the Alnico magnetic alloys, one may expect striking changes in the design of magnets and their application to new appliances. Other notable achievements are in the field of ferromagnetic semi-conductors with high initial permeability, the two- and three-fold increase in the permeability of Permalloys, and the improvements in the performance of iron–silicon and iron–nickel alloys through the control of rolling and recrystallization texture. The article contains 22 German, 6 French, and 10 English and American references. J. G. W.

Steels and Alloys for Magnets. J. Apraiz Barreiro. (Acero y Energia, 1950, vol.7, Mar–Apr., pp. 8–14, 39). [In Spanish]. The basic characteristics of materials for magnets are described. Magnetization and demagnetization curves are discussed. Magnet steels and alloys are classified into four groups: (1) Low-coercive-force steels, including plain carbon, chromium, and wolfram steels; (2) cobalt steels with coercive force above 100 oersteds; (3) nickel–aluminium and nickel–aluminium–cobalt alloys; and (4) other alloys having good magnetic properties, differing from Alnico by being easily workable. The heat-treatment and mechanical working of magnet steels are discussed under the headings of hot working, annealing, hardening, and tempering.—R. S.

Steels for the Manufacture of Transformer Sheet. J. Apraiz Barreiro. (Acero y Energia, 1950, vol. 7, May–June, pp. 33–40). [In Spanish]. The author first defines permeability, hysteresis, Foucault current losses, resistivity, induction, saturation, and modification. Steels for transformer sheets must possess high permeability and have low hysteresis loss. Diminishing grain size, internal stresses due to cold work, precipitation phenomena, and ageing all lead to an increase in hysteresis loss. Transformer sheets must also have high electric resistivity, a high saturation value, and must not be susceptible to ageing. The pros and cons of the types of steels which have been developed for the manfacture of transformer sheet are examined. These include dead soft steels, containing 0·07–0·12% C, 0·10–0·30% Mn, and less than 0·30% Si, which are used for the cores of small transformers where cheapness is required, though their magnetic properties are fairly low. The magnetic qualities of Armco iron are discussed and the effect of heating and of the carbon content on the magnetic properties is illustrated. The magnetic properties of cast iron and of 0·10–0·30% carbon cast steel are mentioned.—R. S.

Ultrasonics and Their Use for Non-Destructive Testing of Materials. N. G. Neuweiler. (Microtecnic, 1950, vol. 4, Jan.–Feb., pp. 37–44; Mar.–Apr., pp. 60–66). Having explained in Part I the piezo-electric effect, the use of quartz crystals, and discussed the velocity of ultrasonic waves in various media, the author in Part II considers the basic working principles of the Henry Hughes Supersonic Flaw Detector together with details of the piezo-electric action of a quartz disc in the transmitter and receiver systems. Typical oscillograms of flows in steel plates and bars are shown using frequencies of $2\frac{1}{2}$, $2\frac{1}{4}$, $1\frac{1}{4}$, and $\frac{5}{8}$ Mc/sec. The coupling medium between probe and sample is usually oil, but improvement may be gained by the use of a medium more closely resembling steel, such as amalgam. In steel forgings where radiographic and other non-destructure methods cannot be employed, a maximum cross-section of 25 ft. may be tested. It is possible in certain cases to determine the size of the flaw.—H. D. W.

Practical Bulb Weld Inspection Using Ultrasonic Flaw Detection. A. C. Rankin. (Welding, 1950, vol. 18, May, pp. 199–209, June, pp. 243–247). The ultrasonic technique for the inspection of bulb welds is described. The function of the newly developed transverse wave probes is to generate or detect a beam of transverse ultrasonic waves which travel at a shallow angle away from or towards the surface of a steel or light alloy section. Ultrasonic energy is emitted in the form of short intermittent pulses each consisting of about a dozen waves, the amplitude decrease of succeeding waves being approximately logarithmic. As each pulse travels away from the transmitter probe it spreads slowly giving a conical beam effect. When a flaw is located by a longitudinal scan, further differentation is possible by moving the transmitter-receiver system round an arc with a flow position in the weld as centre. The oscillogram provides additional information regarding flaws. For example, a flaw lying nearer to or further from the transmitter-receiver system than the centre-line of the weld will show a slight corresponding shift in TF (T = transmission mark, F = flow echoes) on the oscillogram concerned. Maximum amplitude of echo attained in a depth scan provides a rough measurement of flaw size. The transverse wave technique is applicable to sections from about $\frac{1}{2}$ in. thick upwards, and is used for testing pipe welds, flash-bulb welds, and similar cases where radiography has serious limitations.—U. E.

New Inspection Technique Developed. T. A. Dickinson. (Steel Processing, 1950, vol. 36, July, pp. 351, 369). The article describes briefly a new method of surface crack detection, which has been named the Dy-Chek process. A red penetrating dye is applied to the surface under test, and after soaking for 5 min. all the surface dye is removed by a cleaning agent. A white developer solution is then applied, and this causes any red dye which has been retained by flaws, cracks, fissures, etc., to 'bleed' to the surface, thus revealing the flaw. P. M. C.

Progress in the Non-Destructive Testing of Materials by Supersonics. O. Rüdiger. (Iron and Steel Institute, 1951, Translation Series, No. 416). This is an English translation of a paper which appeared in Stahl and Eisen, 1950, vol. 70, June 22, pp. 561–565 (*see* Journ. I. and S.I., 1951, vol. 167, Feb., p. 231).

Ultrasonics and Their Use for Non-Destructive Testing of Materials. N. G. Neuweiler. (Microtecnic, 1950, vol. 4, Jan.–Feb., pp. 37–44; Mar., pp. 60–66). In Part I the theory of the piezo-electric effect of quartz crystals is explained and the construction of a crystal mounting and the circuit of the Sperry Reflectogage are described. The velocities of ultrasonic waves in various liquids and solids are given. The Hughes supersonic flaw detector is described in Part II.—R. A. R.

Processing Steel with Sound. T. A. Dickinson. (Steel Processing, 1950, vol. 36, Sept., pp. 447–451). This is a short analysis and review of the present and possible future uses of ultrasonics in the metal-working field. Ultrasonic sirens which agglomerate industrial smoke particles, reflectoscopes for internal flaw detection, reflectogauges for thickness measurement, and an ultrasonic soldering iron (Mullard) for aluminium are typical well-tried applications. Much research is being carried out on the uses of ultrasonics in metal melting and heat-treatment, and for the dispersal of metallic particles in solutions and for drilling and machining (by local disintegration). A bibliography of 32 references is appended. P. M. C.

Non-Destructive Testing of Castings. L. van Ouwerkerk. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 288–300). [In English]. Magnetic, radiographic, and sonic methods of testing are discussed especially in relation to foundry problems concerning light metal, iron, steel, and copper castings. Some practical examples of application of these methods are illustrated. The difficulty of the supersonic testing of heavy steel forgings having a coarse crystal structure was raised in the discussion. Heat-treatment and a lowering of the frequency or modification of the shadow method are suggested as a means of overcoming this difficulty, though sensitivity is sacrificed.—R. S.

Radon—Its Place in Non-Destructive Testing. V. E. Pullin. (Welding, 1950, vol. 18, Apr., pp. 166–169). The

use of Radon in engineering radiography is discussed. It is successfully used in the examination of high-grade welding up to a thickness of 3 in. and of steel structures up to 9 in. thick. The point source and small focus produce radiographs of excellent definition.—U. E.

Latest Developments in Non-Destructive Testing. O. Vaupel. (Die Technik, 1950, vol. 5, Apr., pp. 155–159; June, pp. 285–288). This is the first measure of a survey of the developments of the last ten years. The author deals with the increased penetration of ultra-hard X-rays produced by betatrons and notes that with 20 MeV. the visibility of details is independent of their depth below the surface up to the limit of penetration (about 500 mm. of steel). He refers also to X-ray discharges, to the development of Geiger counters, and to stereo-microradiography.—J. G. W.

Xeroradiography—A Basic Development in X-Ray Non-Destructive Testing. R. C. McMaster and R. M. Schaffert. (Non-Destructive Testing, 1950, vol. 9, Summer Issue, pp. 11, 22). Xeroradiography is a rapid, low-cost, all-electric method of obtaining permanent X-ray images, in which films and chemical processing are done away with. In place of the usual film, an electrically conductive plate of metal is coated with a smooth layer of a semiconductor sensitive to X-rays. This coating, normally non-conductive, becomes conductive when exposed to X-radiation. The plate, which may be used repeatedly for thousands of exposures, is sensitized to X-rays by 'spraying' a uniform distribution of electrostatic charge upon its surface. On exposure to X-rays, the coating becomes conductive and discharges the electrostatic surface charge into the backing metal. The rate of loss of charge is a direct function of the intensity of X-ray exposure. The 'latent electrical image' is made visible by flowing a special dry 'developing' powder over the plate, the powder adhering to the regions which remain charged. The image may be viewed immediately, or a permanent print may be made in a few seconds. A sheet of ordinary paper is placed over the powder image, and the powder transferred to the paper by the charging machine. Infra-red heat is then applied, and the powder fuses on to the paper.—P. M. C.

A High-Temperature Debye-Scherrer X-Ray Camera. E. C. Williams. (Journal of Scientific Instruments, 1950, vol. 27, June, pp. 154–157). The design of a high temperature camera has been carried out by the Metals Division, Imperial Chemical Industries, Ltd., Birmingham, for Debye-Scherrer examination of flat solid specimens. General features and constructional details of the camera are given. A mechanism of novel design has been incorporated which permits an appreciable surface of specimen to be swept periodically past the incident beam and a simultaneous oscillation about the azimuth to be imposed to bring a large number of grains into reflecting positions. The accuracy of lattice parameter by observations on aluminium and copper is 1 part in 50,000.—

Temperature and Intensifying Screen Effects in Radiography with Cobalt 60. A. Morrison and K. J. Parry. (Non-Destructive Testing, 1950, vol. 9, Summer Issue, pp. 9–10). Radio-active cobalt 60 is used as a gamma-ray source for industrial radiography. The effect of surrounding temperature on film density has been investigated over the range −40° F. to + 140° F. Kodak Noscreen film having 0·017 and 0·022 in. lead front and back screens and 100 mg. radium equivalent of cobalt 60, were used in the tests. It is shown that a linear relationship exists between exposure factor and temperature for a given film density, and under these test conditions, a reduction in temperature from 70° F. to −30° F. would necessitate an increase in exposure time of 25% to obtain the same film density. The authors have also determined experimentally the optimum front lead screen thickness, *i.e.*, that which produces maximum film density for a given exposure factor. This was found to be 0·008 in. using Kodak type A film, an exposure factor of 190, a back lead screen of 0·025 in., and a cobalt 60 source of 1500 mg. radium equivalent at a distance of 30 in. The results of some experiments on the sensitivities obtainable with lead foil and commercial fluorescent screens, are also included.—P. M. C.

Cobalt 60 for Low Cost Radiography. W. Czygan. (Iron Age, 1950, vol. 166, Aug. 24, pp. 68–72). The radio-active isotope cobalt 60 has proved versatile and easy to use for industrial radiography. Chief advantage is the cheapness relative to X-ray and radium sources of equal penetrating power, but the exposure time is considerably longer than for X-rays. The half life of Cobalt 60 is 5·3 years and consequently the exposure time must be recalibrated about every six months to compensate for the loss of strength.—A. M. F.

The Experimental Exploration of Plastic Flow in Metals. L. R. Jackson and W. T. Lankford. (Symposium on Plasticity and Creep of Metals: American Society for Testing Materials, 1949, Special Technical Publication No. 107, pp. 3–11). Data on plastic flow in some sheet steels and copper are reported. It is shown that, when anisotropy in real materials is taken into account, some of the current theory appears to correlate flow results very well both in accounting for the stress required to maintain flow and in describing the distribution of strain resulting from various stress systems.—J. B. B.

Forming Parameters and Criteria for Design and Production. W. Schroeder. (Symposium on Plasticity and Creep of Metals. American Society for Testing Materials, 1949, Special Technical Publication No. 107, pp. 18–35). Forming parameters and criteria are discussed with reference to design and production problems. The results of some of the most significant studies are reviewed briefly. The following specific subjects are discussed: Generalized stress and strain; dimensional similarity; laws of fracture; classification of formed sheet metal parts; basic types of forming action, including bending, stretching, and drawing; and the significant parameters and criteria of these three types of forming. Where these parameters are known to have limited application, these limitations are discussed.—J. B. B.

Use of Creep Data in Design. H. C. Cross and L. R. Jackson. (Symposium on Plasticity and Creep of Metals: American Society for Testing Materials, 1949, Special Technical Publication No. 107, pp. 37–47). Creep data now available are discussed, together with the limitations in their interpolation and extrapolation. The types of additional data which would be of greatest usefulness in the design problems encountered in the use of metals for high-temperature service are indicated.

Super Creep-Resistant Alloys. J. W. Freeman, D. N. Frey, E. E. Reynolds, and A. E. White. (Symposium on Plasticity and Creep of Metals: American Society for Testing Materials, 1949, Special Technical Publication No. 107, pp. 50–68). The available data regarding the factors which control the creep and rupture strength of the 'super alloys,' used in the construction of jet engines, are reviewed. Consideration is given to processing conditions, final treatments, and chemical composition on the basis of available information and theoretical concepts.—J. B. B.

On the Problem of the High-Temperature Strength of Alloys. I. Dekhtyar. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 73, No. 2, pp. 303–305). The physical principles upon which the addition of alloying elements is made to produce steels with high hot strength are explained using the author's data on diffusion.—R. A. R.

Gas Turbine Alloys, 10 Years Later. H. Scott. (Metal Progress, 1950, vol. 58, Oct., pp. 503–511). High-temperature alloys are classified as wrought, or precision cast. They consist of a solid solution matrix of iron and chromium, with enough nickel to provide an austenitic structure at room temperature, and some of the iron replaced by cobalt or more nickel. They are hardened chemically or physically by cold work. After preliminary generalizations, the article deals with the history of high-temperature steels in America, with particular reference to turbo-jet engines. The author points out the need for more uniformity of product, in the future, and considers possible ways of increasing high-temperature strength.—E. T. L.

Iron-Base Heat-Treatable Alloy Has Good High-Temperature Strength. E. F. Losco. (Materials and Methods, 1950, vol. 32, Oct., pp. 65–69). The author gives full details of composition, heat-treatment, mechanical properties, and applications of 'Discaloy,' produced by the Westinghouse Electric Corp. As the name implies, the material was originally developed for gas turbine discs. The nominal composition is 54% Fe, 26% Ni, 13·5% Cr, 3·2% Mo, 1·6% Ti, 0·7% Mn, 0·8% Si, 0·1% Al, 0·03% C, and the material is completely austenitic in all conditions. After solution treatment at 1800 ± 25° F., followed by quenching, the alloy is quite soft (130 to 170 Brinell). After precipitation hardening by holding first at 1350 ± 15° F., and then at 1200 ± 15° F. for 20 hr. in each case, the hardness may vary between 250 and 300 Brinell depending entirely upon the titanium content (this being the hardening element). The alloy has exceptionally high

creep strength, combined with good ductility and excellent oxidation resistance in the range 1000 to 1350° F. The ultimate tensile strength at 1200° F. is above 100,000 lb./sq. in. for the hardened material. Figures are quoted for tensile, creep, and fatigue properties at temperatures up to 1350° F.—P. M. C.

Heat Resistant Castings—Their Selection and Application. H. R. Clauser. (Materials and Methods, 1950, vol. 32, Oct., pp. 79–90). This article is intended to serve as an aid to proper selection, by giving the engineer and designer a comprehensive picture of the standard types and grades of heat-resistant alloys. Three broad groups are considered, Fe–Cr, Fe–Cr–Ni, and Ni–Cr–Fe; chemical compositions, high-temperature strength properties, corrosion resistance, special service properties, and processing characteristics of all these alloys being covered in detail. In addition, the general types of application for which each grade alloy is best suited are given. There are seven references.—P. M. C.

Aircraft Metallic Materials under Low Temperature Conditions. P. L. Teed. (Journal of The Royal Aeronautical Society, 1951, vol. 55, Feb., pp. 61–86). An attempt is made to define the chemical and physical detrimental effects of low temperatures in the metals used in aircraft construction. Part I deals with the chemical aspect, Part II with the physical aspect, and Part III with the engineering significance of the effects of low temperature. Ferritic alloy steels decrease in impact resistance with decrease in temperature. As the sole alloying constituent, nickel has an outstanding influence in reducing this decrease in impact resistance; chromium raises the temperature of transition from ductile to brittle fracture. Hardened and tempered ferritic steels suffer a smaller decrease in impact resistance than when in either the normalized or annealed states. Tables show the changes in impact value with temperature for many ferrous and non-ferrous alloys.—R. A. R.

The Development of Low-Carbon N-155 Alloy for Gas-Turbine Construction. W. O. Binder. (Journal of The Iron and Steel Institute, 1951, vol. 167, Feb., pp. 121–134). The early development of low-carbon N-155 alloy (nominal composition: C 0·12%, Ni 20%, Cr 20%, Co 20%, W 2%, Nb 1%, Mo 3%, N 0·12%, remainder iron) is described, and a study of the influence of hot cold-working (work-hardening at below the recovery temperature), solution annealing, and precipitation hardening on the structure, room-temperature strength, ductility, and impact resistance of the material is reported. Properties at elevated temperatures are reviewed, and creep curves for various stresses at 650°, 730°, and 815° C., extending in some cases from 10,000 to 32,000 hr., are presented; the amount of scatter in stress-rupture test results is investigated and statistically examined. Previous fabricating treatment has a marked influence on the properties of the alloy. Hot cold-working may be utilized for improving hot strength at temperatures up to 650° C., but for uniformity of results the hot cold-working step should be preceded by a solution anneal between 1060° and 1150° C. For high strength at temperatures in excess of 650° C. solution heat-treatment at 1090–1230° C. is recommended. The alloy is subject to some precipitation-hardening during exposure to temperatures in the range 650–980° C., resulting in an increase in strength and a decrease in ductility and toughness at room temperature; though precipitation-hardening heat-treatments are not generally applied in practice, they improve hot-ductility. A study of the properties of sheet indicates that they do not differ significantly from those of bar stock, and the formability of the alloy is shown to be comparable to that of type 347 stainless steel (niobium-stabilized 18/8).

The Occurrence and Some Effects of the Sigma Phase in a Molybdenum-Bearing Stainless Steel Containing 1% Titanium. C. H. Cooke. (Australian Institute of Metals: Australasian Engineer, 1950, Aug. 7, pp. 80–90). This article describes experimental work carried out on the occurrence of the sigma phase in an 18/8 3% Mo 1% Ti steel, and its effects on the structure and mechanical properties. This type of steel exhibits a duplex austenite-ferrite structure in the softened condition, and is therefore prone to the formation of sigma phase if reheated into the range 600–900° C. Specimens were therefore heated for times up to 4 hr. in this range, and the changes brought about by these treatments were investigated by studying the changes in magnetic properties, mechanical properties, microstructure, and corrosion resistance. The experimental procedures and the results obtained are quoted in great detail, the main conclusion being that the formation of sigma phase by the treatment already mentioned, causes a deterioration in physical properties. Sigma-susceptible material is, however, quite suitable for many uses if it is properly softened and never attains temperatures above 500° C. in service.—P. M. C.

Heat-Resisting Steels, Influence of Alloy Additions. G. T. Colegate. (Metal Treatment and Drop Forging, 1950, vol. 17, Summer Issue, pp. 93–101, 109). Various types of heat-resisting steel are considered briefly, details being given of their compositions and properties. Reference is confined to alloys containing at least 50% of iron, such as the straight chromium, straight chromium–nickel, and more highly alloyed chromium–nickel wrought steels, and the iron–chromium, and iron–chromium–nickel cast alloys. The author indicates the effect of small additions of other elements such as silicon, columbium, cobalt, and molybdenum, to each of these types of steel, and includes six tables and five graphs giving details of creep, mechanical, and oxidation resistance properties for most of them.—P. M. C.

Jets Test Designer's and Metallurgists' Ingenuity. R. B. Johnson. (Iron Age, 1950, vol. 166, Aug. 10, pp. 73–78). The author points out that most progress in making better jet engines has been due to design changes. New alloys, heat-treatment, and special processing have only played a secondary part. He cites redesign to combat thermal shock in combustion chambers and diaphragm partitions. Failure of turbine buckets due to fatigue is still a problem.—A. M. F.

Influence of Microstructure on the Hot Strength of Steel. G. Delbart and M. Ravery. (Société Française de Métallurgie: Metal Treatment and Drop Forging, 1950, vol. 17, Autumn Issue, pp. 171–188). This is an English translation of a paper previously published (*see* Journ. I. and S.I., 1949, vol. 163, Dec., p. 473, and 1950, vol. 166, Dec., p. 383).

Physics in the Iron and Steel Industry (6). The Creep of Metals. P. Feltham. (Iron and Coal Trades Review, 1950, vol. 161, Aug. 11, pp. 305–309). The author explains the nature of creep and the significance of the three main sections of the creep curve, and discusses the origin of intragranular and intergranular creep. The application of molecular-rate processes to second-stage creep is considered, and the mechanism of transient creep is discussed. The methods of deriving creep equations are also described.—G. F.

Creep of Steel and Electron Microscope. P. Coheur and L. Habraken. (Proceedings of the Conference on Electron Microscope, Delft, 4–8 July, 1949, pp. 172–174). This paper gives the first results obtained in the authors' research with the electron microscope on chromium–molybdenum steels during creep tests. The steels used had the following approximate composition: 2% Cr, 1% Mo, and 0·1% C. The creep was produced at 550° C. under a stress of 16 to 19 kg./sq. mm. Before the creep test the steel had been normalized at 925° C. and annealed at 775° C. for 6 hr. For the electron microscopic examination the classical process of Formvar replica shadowed with chromium was used. The electronic magnification was 4000 and the photographic magnification 2 to 2·5 diameters.—E. T. T.

Testing Steels for Susceptibility to Creep Embrittlement Using Stirrup-Shaped Specimens and Slow Tensile Tests. W. Ruttmann, G. Bandel, and R. Schinn (Archiv für das Eisenhüttenwesen, 1950, vol. 21, July–Aug., pp. 225–233). The first clearly recognized instance of a deformationless creep fracture is briefly reviewed. Abbreviated tests to assess the susceptibility to creep embrittlement were carried out on stirrup-shaped specimens, some of which were notched, and by means of a slow tensile test. The steels examined were mainly heat-resistant ferritic and austenitic types, and the tests were carried out over the range 450–700° C. With notched specimens it was possible to assess the susceptibility in a short time and by simple means. In the slow tensile test, many steels exhibited, along with a reduced tensile strength, a more or less marked reduction in elongation and, particularly, of necking as compared with their behaviour in normal tensile tests. This reduction of deformability is accompanied by intercrystalline fracture and breaking up of the crystal structure as well as a decrease in impact values. J. P.

Creep Due To Fluctuating Stresses at Elevated Temperatures. H. J. Tapsell. P. G. Forrest, and G. R. Tremain. (Engineering, 1950, vol. 170, Aug. 25, pp. 189–191). This paper describes a series of tests carried out at the Engineering Division of the

National Physical Laboratory in order to examine the creep caused by fluctuating stresses and to compare this with the probable theoretical creep under these conditions. To obtain an estimate of the creep under fluctuating stress conditions from a knowledge of the static creep behaviour, the authors assume that, for any instantaneous value of a varying stress, the creep rate will be the same as in a static creep test at that stress, at the same time from the beginning of the test. In other words that the creep rate at any time is a function of the previous creep history. For the initial study of the correspondence between theory and experiment, static and fluctuating stress tests were made on a normalized 0·26% carbon steel at 400° C. The fluctuating-stress tests were carried out in a Haigh direct-stress fatigue-testing machine at 2000 cycles/min. The experimental results obtained show a trend indicated by the theory. Details of proposed work for future research are given.—M. D. J. B.

The Solubility of Nitrogen in Iron Melts with Chromium, Manganese, and Nickel Additions. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, May–June, p. 203). It is reported that in 1943 the late H. Bischof had found nitrogen contents in iron containing 9·11% Mn or 9·63% Cr at 1550–1600° C. of 0·079% and 0·109% respectively, in good agreement with the values reported later by Wentrup and Reif.—J. P.

Subcritical Graphitization Can Be Controlled. B. F. Brown. (Iron Age, 1950, vol. 166, Aug. 31, pp. 64–68). The graphitization of steel and white cast iron at sub-critical temperature is not a rare occurrence and should be remembered in all applications of carbon-bearing steels stressed as members at temperatures above 750° F. The principles involved are described and it is suggested that the best means of stabilizing the carbide is additions of chromium and tellurium. Oxygen, where deoxidation is necessary, is said also to be a powerful stabilizer; heat-treatment is not considered to be so satisfactory.—A. M. F.

The Effect of Incidental Elements on Carbon Steel Plates. J. G. Althouse. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 171–200). A description is given of tests made on 145 casts of rimmed, semi-killed, and killed plate steels from nine steel companies, in order to determine the effect on the physical properties of the residual elements copper, nickel, chromium, molybdenum, and tin. The properties considered are tensile properties and Charpy impact values between room temperature and 1000° F., weld hardening, precipitation hardening, and hot-working characteristics, and the results show that in all cases the residual elements have no detrimental effect on the physical properties, and in some cases cause an improvement. The maximum amounts of the residuals encountered were approximately 0·4% Cu, 0·13% Ni, 0·05% Cr, 0·02% Mo, and 0·03% Sn.

G. F.

Part I—Composition and Properties of Gray Iron; Part II—Correlation of Properties of Gray Irons. R. Schneidewind and R. G. McElmee. (American Foundrymen's Society, May, 1950, Preprint No. 50-38). The diagrams constructed by Honda and Murakami, and Maurer to correlate cast iron structures with carbon and silicon contents were critically examined, together with the later diagrams by Uhlitzsch and Weichelt. An attempt is presented to reduce the relationships defined in the diagrams to a more quantitative basis, and a mathematical expression has been derived to show the limiting compositions with respect to carbon and silicon which will cast white. These values are restricted to normal irons, unalloyed and not inoculated, over a range of section sizes cast in sand. A correlation has also been made between carbon equivalent and the tensile strength and the section size for sand castings. In addition, a method is proposed to compute the probable strength of sand-cast grey irons of varying sections when alloyed. A statistical study of over 300 heats of plain and alloyed irons showed that nearly 75% of the reported properties of these irons fell within ± 10% of the predicted values and between 85 and 90% fell within ± 15% of the predictions. There are 49 references.

E. J. D. S.

Ductile Iron—in Light Sections. E. J. Laufer. (Iron Age, 1950, vol. 166, Aug. 10, pp. 79–82). The Acme Shear Co. has a production of over 5 tons/day of light castings of ductile iron. They vary from ½ oz. to over 40 lb. and the yield strength is at least 50% greater than forged steel or malleable iron. Gates must be specially designed and proper precautions taken against shrinkage. Annealing produces the maximum ductility, toughness, and machinability.—A. M. F.

Ductile Iron for Heavy Machinery. C. D. Galloway. (Iron Age, 1950, vol. 166, Aug. 3, pp. 75–78). Extensive tests on the casting of ductile iron have been carried out by the Chambersburg Engineering Co., Pa. This iron is a high-silicon steel containing free graphite in spheroidal form. The matrix may consist of silico-ferrite, pearlite, cementite, and phosphide in direct relation to composition, cooling rate, and heat-treatment. Confirmatory tests on a great many of the special properties previously announced have been carried out and in addition the damping quality has been found to be much better than previously thought, the linear shrinkage is almost identical with that of cast iron and the material has high hot strength and thus requires no special moulding or sand practice.—A. M. F.

Nodular Iron's Record—Two Years Later. (Steel, 1950, vol. 127, July 17, pp. 85–89, 100). The editors of *Steel* have asked all licensees under the International Nickel Co's patents for magnesium-treated nodular cast iron to comment on their experience with the material, and reports are given on the material's usefulness. A wide variety of castings have been made, from a 6500-lb. hammer cylinder to lawn-mower parts. The ductility, machinability, toughness, and weldability of the castings indicate that it should be a useful engineering material; but one producer found that for light sections they could not obtain such satisfactory results as with malleable iron.—A. M. F.

High Strength Steels. C. L. Altenburger. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 278–292). The author discusses the properties of low-alloy high-tensile steels and presents data on their welding, pressing, stamping, and drawing characteristics. Some of the factors to be taken into account in the design of structures are briefly considered.—G. F.

"Super Machining" Steels Increase Production 100%. E. F. Ross. (Steel, 1950, vol. 127, July 31, pp. 60–62, 84–89). Super-machining screw stock steels are showing spectacular improvements in machinability and fabricating characteristics. These materials are of two general types, improved free-machining Bessemer steels and lead-bearing rephosphorized and resulphurized open-hearth steels. The steels are: (1) MX, a Bessemer steel which depends for its properties on its percentages of carbon, silicon, and manganese and the nature of its sulphide inclusions. The carbon is 0·03% max. and is usually 0·06–0·07%. (2) E, which is a non-rimming Bessemer steel deoxidized with medium carbon ferromanganese, in the grades equivalent to B-1111, B-1112, and B-1113 but with reduced carbon, this being 0·04–0·06% compared with 0·08–0·13% for corresponding grades of the old screw stock. (3) The present product of open-hearth Ledloy has a very fine even dispersal of lead particles through the bar, a typical specification is C 0·10%, Mn 0·95%, P 0·07%, S 0·27%, Pb 0·21%. These materials have a slightly lower tensile strength and are softer than their corresponding S.A.E. grades, but this is not noticeable for most products.

A. M. F.

Merchant Wire Products. H. A. Caldwell and C. L. McGowan. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 223–230). The manufacture and properties of steel wire are briefly discussed, and some of the chief items classified as 'merchant wire' and 'merchant wire products' in Section 16 of the American Iron and Steel Institute's Steel Products Manual, are listed.—G. F.

Wire Rope—Usage, Care, Maintenance. A. J. King. (Iron and Steel Engineer, 1950, vol. 27, May, pp. 102–107). The development of rope through the ages is briefly described after which the author discusses the fabrication of modern wire rope, the multiple usages, the design, and the different types and grades. Briefly, these fall into three general types: (1) Coarse or hard laid, (2) medium or soft laid, and (3) special or extra flexible laid. These and other types are considered in detail. The need for care in handling wire rope is stressed and recommendations are given which should contribute to lengthen its life. The importance of proper maintenance both to rope and sheaves is also stressed.

M. D. J. B.

Effect of Cold Work at Low Temperature on Austenitic 18-8. W. O. Binder. (Metal Progress, 1950, vol. 58, Aug., pp. 201–207). Strain on austenitic 18/8 steel at low temperatures has the effect of causing some transformation to martensite.

However, this is slight and causes little decrease of impact strength. To cause transformation, strains greater than 0·2% are needed; such strains are rare in practice, so that austenitic 18/8 steel is suitable for service at low temperatures. E. T. L.

Metallurgical Problems in Oil Well Drilling and Petroleum Production. G. W. Whitney and M. Spar. (Metal Progress, 1950, vol. 57, June, pp. 755–760). Derricks for drilling oil wells are now of low-alloy steel for greater corrosion resistance and weldability. Similar changes have taken place in the metallurgy of derrick equipment, and power transmission shafts, slush pumps, drill pipe and casing, and sucker rods. Most failures are due to faulty design (or operating conditions) rather than defective metal.—E. T. L.

Stainless Steel for Television. A. S. Rose. (Metal Progress, 1950, vol. 57, June, pp. 761–764). The glass face of a television receiver screen is sealed to a core of ferritic stainless steel, which is chosen for its expansion characteristics since these affect the vacuum tightness of the seal. By adding small quantities of titanium or niobium, it is possible to use a steel with 17% chromium, instead of the more costly 28% chromium steel since the additions suppress the volume change at the α–β transformation.—E. T. L.

Development and Present Position of Rolled and Forged Stainless Steel. K. Bungardt. (Stahl und Eisen, 1950, vol. 70, July 6, pp. 582–596). Stainless steels are ferrous alloys with at least 12% of chromium and the main considerations for their use are corrosion resistance, adequate strength and, in most cases, good weldability. For some applications good machinability is also desirable. The scientific investigations carried out to assess and explain the corrosion resistance of stainless steels, particularly under conditions of stress, are fully described and the two main theories, that of electron displacement of Uhlig and Wulff and that of superficial oxide formation due to Evans and Müller, are explained. Although much development work has been carried out in recent times, it can be said that the essential composition of stainless steels has remained unchanged since 1939. The attempts before 1939 and during the war to economize in nickel, and to some extent molybdenum, produced useful results, though it was realized that such lower alloyed steels have restricted serviceability. Now that metal supplies are no longer so restricted, the tendency is to return to the proved 18/8 varieties. Experience in Britain and America has been along the same lines as in Germany and the development of steels for special applications follows the same basis in all three countries.—J. P.

Development and Present Position of Cast Stainless Steel. K. Roesch. (Stahl und Eisen, 1950, vol. 70, July 6, pp. 596–606). Although the amounts of cast stainless steel are small compared with that rolled or forged, there are some components which can be made economically only by casting. As with rolled and forged, there are also three alloy groups of cast stainless steel, *viz.*, sorbitic, ferritic-carbidic, and austenitic. The ferritic-carbidic steels are of particular importance for casting because their high carbon and silicon contents make them easily castable and they exhibit their maximum corrosion resistance without heat-treatment. For good corrosion resistance in the annealed and cast states, the chromium ferrite must contain at least 12% of chromium and, in addition, to bind the carbon as 'noble' carbide, $(CrFe)_4C$ or $(CrFe)_{23}C_6$, approximately 16 times as much chromium as carbon is needed, *i.e.*, chromium content = $12 + 16 \times \%C$. When sorbitic-martensitic steel with 14–18% of chromium is heat-treated and then tempered at approximately 500° C. it exhibits its minimum resistance to corrosion. Such a steel must therefore be used in the hard or fully annealed state. The choice of alloy frequently depends upon mechanical requirements. In many cases the corrosion resistance of cast steel with 30% of chromium is equal to that of 18/8, but from strength requirements the latter must be chosen. On account of the tendency to fretting corrosion, only hardenable steels with 14–18% of chromium can be used under conditions of sliding friction. The influence of nitrogen in refining the grain of ferritic steel with 30% of chromium has been investigated and it has been shown that nitrogen, like titanium, has a deleterious effect, since, though it does refine grain, it increases brittleness. The types of cast stainless steel used in America do not differ essentially from those used in Germany, since the attainment of passivity necessitates a minimum content of chromium. Steels with approximately 28/4 or 29/9 chromium–nickel, are frequently employed because, in contrast with 18/8, they do not require to be heat-treated. For alloys resistant to H_2SO_4 or HCl over a wide range of concentrations, passivity due to chromium plays no part. Under these circumstances, nickel-molybdenum alloys are used with more than 15% of molybdenum and only little iron.—J. P.

Influence of Alloy Additions on the Diffusion of Hydrogen in Iron: the System Iron–Hydrogen. W. Geller and Tak-Ho Sun. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Nov.–Dec., pp. 423–430). Thermodynamic consideration of the results in the literature has led to expressions for the temperature dependence of the solubility of hydrogen in pure iron. On this basis, the phase boundaries in the iron corner of the iron–hydrogen equilibrium diagram have been calculated. Experiments on the evolution of hydrogen from very low carbon steels at room temperature have shown that, along with the known effects of lattice and microstructure and the indirect influence of alloy elements on these, there can exist a direct effect of the dissolved elements. The retardation of hydrogen evolution by elements dissolved in ferrite is closely connected with their affinity for hydrogen and can be so great as to suppress hydrogen evolution completely. The rate of evolution cannot be predicted theoretically since it would be necessary to assume that diffusion is the rate-determining factor; at room temperature, processes of transfer from solid solution to gas phase are rate-controlling. The diffusion coefficient of hydrogen and its temperature dependence have been determined from permeability measurements at elevated temperatures, making suitable assumptions as to the solubility of hydrogen in ferritic alloys with 1–4% Si or 27% Cr and in 18/8 austenitic steel. Additions of silicon and chromium reduce the diffusion coefficient. As the coefficient decreases, so does the activation energy, calculated from its temperature dependence. There is a qualitative relationship between diffusion coefficient and hydrogen evolution at room temperature; below a value of approximately 10^{-10} sq. cm./sec. no hydrogen evolution is to be expected.—J. P.

Research Shows How Pickling Causes Brittleness in Stainless Steels. C. A. Zapffe. (Materials and Methods, 1950, vol. 32, Oct., pp. 58–62). The absorption of hydrogen from pickling solutions, and the formation of high-pressure gaseous cavities, are briefly described as the cause of hydrogen embrittlement. Bend tests on stainless steel type 410 (12% Cr), show that the material is more susceptible to embrittlement when in the hardened condition, and that cold working increases this susceptibility in any condition. On a basis of equal normalities, it has also been shown that all acids cause equal severity of embrittlement. The author also mentions the fact that small traces of sulphur, phosphorus, arsenic, selenium, antimony, and tellurium, if present in pickling solutions, may increase hydrogen absorption to a very great extent.—P. M. C.

A Special Case of Carbon Diffusion: From Cast Iron to Cast-In Steel. J. E. de Graaf. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 106–117). [In English]. When iron is cast around forged steel, as is sometimes done with crane hooks and cooling pipes, some carbon migrates into the steel. This diffusion was investigated using forged 10-mm. dia. bars of 0·1% carbon steel. The effects of silicon, aluminium, nickel, chromium, wolfram, and manganese on the diffusion were also studied. The absorption and diffusion of the carbon is mainly related to the solubility of the carbon in the austenite and not to the diffusion coefficient. Absorption is thus diminished by elements which reduce the austenite phase. The experiments confirmed this except in certain cases of sluggish transformation.—R. A. R.

Development of Chromium–Manganese Stainless Steels Using High-Purity Electrolytic Manganese for Alloying. D. N. Dhanbhoora and J. S. Vatchagandhy. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 309–331). Investigation has been made into the effect of replacing nickel, wholly or in part, in 18/8 austenitic stainless steel by high-purity manganese metal, now produced in India. A series of alloys with varying carbon, nickel, and manganese contents was prepared in a laboratory high-frequency furnace

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and forged into bars. A close study was made of their microstructures and the results correlated with knowledge gained from a study of phase diagrams of the ternary Fe–Cr–Mn system. By means of standardized laboratory tests, the corrosion resistance of the alloys to atmospheric conditions, salt spray, nitric acid, sulphuric acid, intergranular attack, and high-temperature oxidation was determined and compared with that of a standard 18/8 stainless steel tested simultaneously. The yield strengths, tensile strengths, reduction in area, and elongation of the alloys were compared. From the results it is concluded that low-carbon 18% chromium steels in the alloying range of 4–12% manganese, and 0·4% nickel hold considerable promise of being developed industrially to take the place of conventional 18/8 stainless steels for most commercial purposes.—D. H.

Steels for Tapered Roller Bearings. J. H. Evans. (Metallurgia, 1950, vol. 42, Aug., pp. 140–144). A description is given of the general and metallurgical requirements of steels for tapered roller bearings. It is pointed out that tapered roller bearings are always made of case-hardened steels, and that the steels to be used must have reproducible case-hardening characteristics, and must produce an even case free from soft spots. They must be, to a very great degree, free from stringer-type inclusions and show very small deformability on machining. Detailed metallurgical requirements are given for nickel–molybdenum and nickel–chromium case-hardening steels. Eight microphotographs are given in illustration of points made in the text.—J. J.

High-Duty Steel Castings. F. Harms. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1950, vol. 5, June 15, pp. 194–201 ; July 15, pp. 243–247). The author reviews the historical development of high-duty steel castings, and discusses the alloying elements in use and the modern trend towards minimizing alloy additions and securing the required properties largely by correct production methods and heat-treatments. Alloy steel castings are used, particularly in the aircraft and automobile industries, with tensile strengths up to 125 kg./sq. mm. The compositions and tensile and impact properties of a number of chromium, chromium–molybdenum, chromium–vanadium, and manganese–vanadium steels are given and examples of their use are illustrated. The compositions and uses of the Ford copper-bearing cast steels used for tractors are also listed. For boilers, turbines, armaments, and similar work, castings with high creep strength at elevated temperature are required. The compositions and tensile, impact, and creep properties of a number of suitable steels, mainly chromium–molybdenum steels with sometimes the addition of further elements, are listed. The compositions, tensile, bending, and impact strengths, and hardnesses of a range of high-alloy chromium, chromium–nickel, and chromium–manganese steels for resistance to rusting and chemical attack are tabulated, and examples of suitable uses of the different types are given. Heat-resistant cast steels for temperatures ranging from 850 to 1200° C. are available, chromium–silicon steels being suitable for the lower, and chromium–nickel–silicon steels for the higher, temperatures ; their composition and tensile properties are quoted. The use of cast steels for bells and for the tools used in hot working of metals are also discussed.—H. R. M.

Weldments or Castings. M. R. Nelson. (Iron Age, 1950, vol. 166, Sept. 14, pp. 93–100). The use of Meehanite castings with a yield point very near the breaking strength provides in certain instances stronger and cheaper parts than welded structures. Welding steel has a yield point of 30,000 lb./sq. in. while castings have yield points close to 50,000 lb./sq. in. For certain applications cast worm gears have also been found to be better as well as cheaper than forged steel.

A. M. F.

A Nickel–Chromium–Iron Alloy for Sealing to Glass. J. E. Stanworth. (Journal of Scientific Instruments, 1950, vol. 27, Oct., pp. 282–284). The development is described of a nickel–chromium–iron alloy (Ni 47%, Cr 5%) and an ordinary lead glass as used in the manufacture of lamps and valves. Stresses in seals made with these materials are low at all temperatures, even although there is a 60° difference between the Curie temperature of the alloy (about 340° C.) and the glass transformation temperature (about 400° C.). Various alloy compositions are given, and the results of stress–temperature measurements are summarized by curves. Final comparison is drawn between C_{40} borosilicate glass to Kovar type alloy and C_{12} lead glass to nickel–chromium–iron alloy.

METALLOGRAPHY

The Present State of Microscopy. B. von Borries. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, Apr., pp. 240–247). After pointing out the overwhelming contribution made by optical microscopy to the morphological branch of most natural sciences, the author turns his attention to the present state and the future of electron microscopy. He claims that up to the end of the war Germany was leading the world in the technical development of electron microscopes, but that now, owing to the paucity of instruments in the country, Germany tends to lag behind other nations. He discusses the chief problems of this technique, the basic design requirements, and the techniques of preparing specimens. It appears that Germany possessed a total of 45 electron microscopes at the end of the war which shrank to 10 in 1948, an estimate of 300 is made for the U.S.A., Great Britain being third with about 40 in 1948. Thirty-six references are quoted.—J. G. W.

The Structure of a Metal Surface. A. J. W. Moore. (Australian Institute of Metals : Australasian Engineer, 1950, Oct. 7, pp. 65–68). After a description of the Van der Waals forces and the chemisorption which can be predicted from the application of probability functions, the author shows how metal surfaces encountered in practice compare with this simplified picture. Real surfaces show large irregularities in contour, relatively thick films of foreign atoms, and considerable deformation at or near the surface. The techniques for the measurement of these surface features (electron diffraction, multiple beam interferometry, electron and optical microscopy, etc.) and the types of result obtained, are described. There are 19 references.—P. M. C.

Replica Techniques in Electron Microscopy. A. W. Agar and R. S. M. Revell. (British Journal of Applied Physics, 1951, vol. 2, Jan., pp. 8–11). Precautions for obtaining clean and reliable replicas for the study of large areas of metal surfaces are outlined. Modifications to the backed replica technique, and the application of preshadowing in metallographic studies are described.—R. A. R.

The Determination of Electron Microscope Magnification. R. S. Pease. (Journal of Scientific Instruments, 1950, vol. 27, July, pp. 182–186). Electron microscope magnifications are usually measured by the use of diffraction grating replicas as standard objects. Replica materials of plastic, gold-shadowed silica, and metal are discussed. The average error of magnification determination in terms of lens currents using copper replicas is about 2·5%. A method in which movement of the object and image are measured and compared is described, movement of the specimen being measured by a variable gap Fabry-Perot interferometer. When specimen movements of 5μ were obtained, interferometer measurements gave results to within 1%. A well-made calibrated fine control for the measurement of specimen shift would give this accuracy with the minimum of trouble to the operator.

Examination of the Structure of Lamellar Pearlite and of Pearlitic Structures in a Chromium Magnet Steel with the Electron Microscope. Angelica Schrader. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Sept.–Oct., pp. 337–343). Electron photomicrographs were taken by the aluminium oxide replica method of different pearlitic structures. The individual stages of the method were tested and the relationship between the form of the oxide film and that of the etched metal surface studied. It is considered that with coarse lamellar or grainy pearlite, the carbide is not attacked by the etching reagent or attacked only at its edges, whereas with fine pearlite there is a more marked attack on the lamellæ. This causes the difference in profile height between ferrite and carbide to be smaller, so that the electron microscope picture shows a less distinct structure. Investigation of the pearlitic transformation structures of a chromium magnet steel, shows that the aluminium oxide replica technique permits of the recognition of more detail than does the ordinary optical examination of the etched section. There is good agreement between the structure pictures so obtained and those of the electrolytically isolated carbides.—J. P.

Emission Microscopy in Metallurgical Research. W. G. Burgers and G. W. Rathenau. (Proceedings of the Conference on Electron Microscope, Delft, 4–8 July, 1949, pp. 81–83). At the Philips' laboratories an emission microscope is being developed. This instrument has an accelerating field and three magnetic lenses. Several investigations are in progress.

In a preliminary investigation the γ-α transformation of iron has been again examined. Instead of a steep temperature gradient such that α-grains were always present in the colder parts of the specimen, a lower temperature gradient has now been used; thus, not only the growth but also the nucleation of α-crystals could be followed.—E. T. T.

Elektron Micrography. J. Ternisien. (Microtecnic, 1950, vol. 4, Mar.–Apr., pp. 82–88; May–June, pp. 137–142; July–Aug., pp. 189–193). A brief outline of the scientific principles on which the construction of electron microscopes with magnifications up to some tens of thousands is given, supported by basic velocity and energy calculations. Comparisons are drawn between electrostatic and magnetic electron lenses, with special attention being paid to inherent aberration. A detailed analogy is drawn with the optical microscope, the resolving power of which is limited by the nature of visible light. The electrons make it possible to distinguish 2500 details in a small spot furnished by the optical instrument. The imperfections of the image evolve from a combination of errors owing to a lack of sharpness, produced by spherical aberration, and due to defraction; a compromise is the only practical solution. Details of commercial electron microscopes by Radio Corporation of America, the General Electric Co., and C.S.F. are given together with special methods of mounting objects. Attention is drawn to the advantage of the high resolving power of these microscopes in metallurgical applications, illustrated by laboratory micrographs.—H. D. W.

The Electron Microscope in Metallurgy. A. L. Ellis. (American Iron and Steel Institute: Blast Furnace and Steel Plant, 1950, vol. 30, June, pp. 681–686). The author used, for his electron microscope studies, what was essentially the negative plastic replica method of Schaefer and Harker. He describes some work done to confirm the reliability of this method. Details and illustrations are given of the attempts made to correlate the mechanical properties of steel with its structure.—J. P. S.

The Core of Graphite Spherules in Nodular Cast Iron. A. L. de Sy. (Metal Progress, 1950, vol. 57, June, pp. 774–775). An electron microscope study showed a distinct nucleus in graphite spherules, which subsequent chemical tests showed might be a magnesium compound.—E. T. L.

New Optical Instruments for the Inspection of Products and Examination of Materials. A. Metz. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, May 1, pp. 323–331). Instruments are described, which were shown at an exhibition for precision measurements in Frankfurt a. Main in October 1949. Among these is a new Leitz universal projector with both dia- and episcopic projection; and a 'Perflectometer,' also by Leitz, which employs a new principle for the measurement of conical holes and gauges. The usual method, in which one focuses on the edge of the object, suffers from the interference of random reflections. In the Perflectometer the surface of the object is made to reflect the real image of a line and the reflection is observed in a microscope. The Perflectometer is built into an Abbe comparator. Among other instruments described are: a Leitz optical dividing head, Zeiss and Askania interferometers, and Leitz surface roughness measuring apparatus of the Forster type in which the sapphire probe, instead of moving along the surface is lifted periodically, touching it at intervals of $0{\cdot}2\mu$, and the profile is determined with an accuracy of $0{\cdot}1\mu$. Also mentioned are metallurgical projection microscopes, dilatometers, and hardness and microhardness testers, chiefly by Leitz.—J. G. W.

Grain Size Measurement. G. T. Callis and R. S. Moore. (Metal Industry, 1950, vol. 77, Aug. 4, pp. 67–68, 71). The authors describe a simple instrument, which, when fitted to a microscope stage, enables the line intercept method to be used without its customary tedium. A specimen carrier is moved relative to a scale by means of a fine-pitch screw, and this complete unit is itself moved relative to a fixed base by a second screw, both movements being in the same straight line and direction. The image of the specimen is traversed past a datum point marked on the screen or in the eyepiece, the traverse of the two phases being effected by the two screws, one for each phase. All the intercepts of each phase are totalled and read off opposite sides of the scale, thus enabling the proportions of each to be easily determined.—P. M. C.

The Measurement of Grain Size on Metal Sections. H. Kostron. (Stahl und Eisen, 1950, vol. 70, Aug. 3, pp. 713–715). The various methods which have been described for the rapid evaluation of grain size by comparison of standards with enlarged images of the metal section are briefly discussed. The methods mentioned are those of the A.S.T.M., of Petersen, and of Dederichs and Kostron. The methods of point counting and linear analysis for grain size and phase distribution in two-phase structures are also mentioned.—J. P.

Micrographic Detection of Temper Brittleness in Low-Alloy Steels. P. A. Jacquet. (Académie des Sciences: Sheet Metal Industries, 1950, vol. 27, June, pp. 511–512). A brittle condition can be induced in certain low-alloy carbon steels by very slow cooling from a tempering temperature of about 625° C. Water quenching from this temperature produces a tough condition. The author states that in the brittle state the grain boundaries are narrower and more clearly defined than in the tough condition. This difference can be detected if the specimen is electrolytically polished before etching. Mechanical polishing, however carefully done, disturbs the normal structure and masks the difference.—P. M. C.

A Note on the Orientated Overgrowths of Metal Films on Single Crystal Inorganic Substrates. H. R. Thirsk. (Proceedings of the Physical Society, Section B, 1950, vol. 63, Nov. 1, pp. 833–839). Some new examples of metal crystal orientations on inorganic substrates are described. They include silver and iron on mica, iron on potassium chloride, platinum on the cube face of potassium chloride, silver and nickel on the cube face of magnesium oxide. The orientations were studied by means of electron diffraction. Some of the problems involved in the study of the types of crystal growth are discussed briefly for the cases examined.—C. J. B. F.

The Anomalous Cementation Behaviour of Steel. W. A. Fischer and W. Koch. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Sept.–Oct., pp. 345–354). In normal cementation structures the cementite strings between the grains are thin and the pearlite extends right to the grain boundaries. In anomalous structures the strings are coarse and are surrounded by areas of ferrite, with pearlite only in the middle of the grains. Anomalous structures do not occur if the sample is quenched rapidly after carburizing. Iron melts were made in basic and acid high-frequency furnaces and deoxidized to different extents with a range of single metals or of Fe–Mn–Si alloys. Samples of these melts were tested for susceptibility to ageing and for their cementation behaviour. The oxidic inclusions were also isolated electrolytically and their appearance and composition determined. It was established that there was anomalous cementation when the FeO content of the inclusions was greater than 10%. No correlation could be found between the composition of the inclusions and the ageing behaviour. As a result of these investigations it was concluded that anomalous cementation is due to an increased diffusion rate of carbon in γ-iron at the Ar_1 point which is obviously connected with the form of combination of the oxygen contained in the iron.—J. P.

The Measurement of Internal Stresses of the Second Type. P. Skulari. (Iron and Steel Institute, 1951, Translation Series, No. 413). This is an English translation of a paper which appeared in the Czech journal Druhý Pracovní Sjezd Hornich a Hutních Inženyrů, 1949, May, pp. 127–144. *See* Journ. I. and S.I., 1950, vol. 166, Oct., p. 163.

Note on the Theory of Alloys. N. S. Akulov. (Doklady Akademii Nauk S.S.S.R., 1949, vol. 66, No. 3, pp. 361–364). In this mathematical paper the influence of order-disorder relations of atoms in crystals in alloys on the magnetic properties is dealt with.—R. A. R.

Phase Contrast Metallography. R. L. Seidenberg and J. R. Benford. (Metal Progress, 1950, vol. 58, Nov., pp. 725–728). Phase-contrast microscopy is a new addition to the use of bright field, dark field, or polarized illumination. The advantages of each are considered. The normal bright-field microscope is converted to phase-contrast metallography by inserting an annular stop in the illuminating system, and a phase disc in the image of the stop; details of such a conversion are given, with references. Some photographs compare the results of bright-field and phase-contrast metallography, and show that the latter gives slightly better contrast. There is also some information on the relative depression of adjacent crystals.—E. T. L.

Electron Diffraction Study of Some Reactions and Surface Structures in the Case of Metals. (Method of Vacuum Polishing). R. Courtel. (Métaux et Corrosion, 1950, vol. 25, May, pp. 117–125; June, pp. 145–155; July–Aug., pp. 188–199).

The author describes his 40-kV. apparatus (using the diffraction of high-velocity electrons) for the preparation of specimens for surface examination by diffraction. The method can be used to study the type of destruction accompanied by a reorganization of the external layers of a metal. The apparatus is a development of J. J. Trillat's apparatus and consists of a normal diffractograph with a hot cathode, without electronic optics and with plane or conical lubricated grinders. An electric device adapted to high-speed grinding at 45,000 r.p.m. in a vacuum is described. Details of grinding and polishing operations, and the choice of grinding wheels are given. The author discusses the Beilby layer controversy and the third halo which he ascribes to an adsorbed layer of degreasing solvent. This third halo does not appear in the case of specimens which have been vacuum-polished before examination. Vacuum-polishing permits a qualitative study of adsorption and chemisorption in a cold gaseous atmosphere. It offers possibilities in the little-studied field of reactions at 100° to 400° C. The elimination of the induction period accompanying the habitual presence of adsorption films or oxidized layers on abraded surfaces in air is of great potential value. The study of lubrication phenomena will also profit from the application of this method. In the second part the author describes the classification of the preferential orientations of surface crystals due to grinding. He indicates how the method of observation has an important bearing on the apparent character of ground surfaces. Taking the case of cobalt, he describes the experimental determination of the surface temperature during grinding. Previous work on the determination of the thickness of the work-hardened layer and the theory of the phenomenon of hardening by conduction are discussed in the light of the author's own experiments. Oxidation phenomena during grinding in a rarefied atmosphere are examined. There is a definite relationship between oxidation, temperature, and speed of grinding. Vacuum grinding plus electronic diffraction observation of surfaces serves both as a metal physics technique and as a special method of surface treatment. In both cases, use is made of the considerable disturbance caused by grinding, which completely reorganizes certain layers of metal in a very short time. A study of the parts played by the physicochemical factors is thus facilitated. Suggestions are offered for improving current equipment.—R. S.

On the Metastability of Iron–Carbon Alloys K. P. Bunin and N. M. Danil'chenko. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 72, No. 5, pp. 889–890). The importance of self-diffusion of iron atoms to the formation of graphite in iron–carbon alloys is studied with special reference to the energies of activation required by the different processes. The effects of preliminary quenching, plastic deformation, interdendritic shrinkage, and the addition of silicon on graphitization are explained. The addition of silicon distorts the packing of the iron atoms in austenite and ferrite which accelerates the self-diffusion of the iron atoms in these phases.—R. A. R.

The Mechanisms of Diffusion. P. J. Fensham. (Australian Institute of Metals: Australasian Engineer, 1950, Oct. 7, pp. 69–71). Several possible mechanisms for diffusion are discussed in terms of the atomic arrangement in solids. Theoretical and experimental evidence is presented which indicates that diffusion in solids may occur by means of the vacancies or lattice defects existing in solid crystals. There are 17 references.—P. M. C.

The Effect of Diffusion on Structure in Alloy Systems. R. L. Kamm. (Australian Institute of Metals: Australasian Engineer, 1950, Oct. 7, pp. 72–75). Most impregnation processes involve changes in microstructure of surface layers. The principles governing the formation of these new structures are described. After a theoretical discussion of the mechanism of impregnation and the uses of the laws of diffusion to calculate depth of penetration, the structures developed during impregnation of pure metals and binary alloys are treated using the equilibrium diagram, although non-equilibrium conditions prevail. The deviations from equilibrium are described, and oxidation is treated in some detail. There are 23 references.—P. M. C.

Atomic Diameter of Metallic Elements. P. Duwez. (Metal Progress, 1950, vol. 57, Mar., pp. 348, 348-B). A chart relating atomic diameter, electron configuration, and crystal structure, which are the three factors governing metallic solid solution, is presented. It makes possible an easy determination of elements having a diameter within a certain percentage of that of any selected element.—E. T. L.

Examination of Metals under Polarized Light. I—Theory and Apparatus. B. W. Mott and H. R. Haines. (Research, 1951, vol. 4, Jan., pp. 24–33). The theoretical basis of the examination of metals under polarized light is reviewed, and the types of apparatus required are described. The reflection of polarized light from cubic materials, uniaxial crystals, orthorhombic crystals, monoclinic and triclinic crystals, and transparent inclusions in metals, is discussed theoretically. Also reviewed are the effects of anisotropic surface films and surfaces subjected to controlled attack by etching, on reflected polarized light. Types of apparatus described include vertical illuminators, objective lenses, polarizer and analyser units, a sensitive tint plate, types of illuminant, and photometers. Seventy references are given.—C. J. B. F.

The Crystal Structure of Graphite in Cast Iron. W. S. Owen and B. G. Street. (Journal of The Iron and Steel Institute, 1951, vol. 167, Feb., pp. 113–116). The crystal structures of (*a*) graphite extracted from an iron–carbon–silicon alloy prepared from high-purity materials, and (*b*) graphites from a variety of commercial cast irons, have been studied by the X-ray powder method. In all cases the structure was a mixture of the α and β structures found in other graphites of different origin. The proportions of α and β structures present vary considerably in the different forms of graphite, and a correlation between the microscopic appearance and the crystal structure has been established. The parameters of the unit cells have been measured, and as no variation from the accepted value for pure graphite has been found, it is concluded that the graphite occurring in iron–carbon–silicon alloys and in commercial cast irons is appreciably pure carbon.

An X-Ray Method for the Study of Phase Changes at High Temperatures. H. T. Heal and H. Mykura. (Metal Treatment and Drop Forging, 1950, vol. 17, Autumn Issue, pp. 129–135). A method of studying phase transformations in solids by continuously measuring the intensity of X-rays diffracted from one set of crystal planes is described. This uses a bent-crystal monochromator, Seeman-Bohlin focusing, and a Geiger counter as detector. The counter output is recorded *via* a counting-rate meter, a double-beam monitoring system being used to compensate for fluctuations in X-ray output. An S-curve for a 2½% Ni steel thus determined shows fair agreement with curves obtained by the standard microscopic technique. The method has the advantage that it can be applied to transformation studies during continuous cooling and in the martensite region. Also in transformations where more than two phases appear, observations can be made directly on the separate phases.—P. M. C.

Gamma Ray Metallography. J. Ternisien. (Microtecnic, 1950, vol. 4, Sept.–Oct., pp. 269–275). Whereas X-rays possess wavelengths from 0·250 to 0·075 Å., gamma rays emitted by certain radio-active elements possess wavelengths from 0·040 to 0·005 Å. and they are much more penetrating. The penetrating power of X-rays is limited to some 150 mm. of steel, gamma rays make possible the examination of steel 250 mm. thick. The source of radiation is a preparation of mesothorium or a radium salt which is contained in a hermetically closed silver or platinum tube. The tube containing the preparation is placed inside (in the case of a tubular piece) or behind the part to be radiographed, and the photograph is taken on the other side. For this purpose a film is inserted in a light-proof wrapper which is applied to the piece previously covered by a sheet of rubber sponge. A second rubber sheet covered by a sheet of lead 4 to 5 mm. thick is applied to the exterior to serve as a protection against radiation. Exposure time is long. For a piece 150 mm. thick, for example, and with the radium source at a distance of 470 mm., an exposure time of 20 hr. is required. Its advantage consists in making it possible to examine very thick parts, particularly hollow or intricate ones, inside which it would not be possible to arrange a large X-ray tube. Another method consists of immersing the piece to be tested in a liquid made radio-active by a thorium salt. The liquid is subjected to high pressure and penetrates into the cracks. The fraction of the liquid retained by the defects is revealed photographically or electrically by measuring the ionization with a Geiger-Müller counter.—E. T. T.

Experimental Determination of the Effective Depth of Penetration of X-Rays in Stress Determinations. A. Schaal.

XUM

(Zeitschrift fur Metallkunde, 1950, vol. 41, Sept., pp. 293–295). The author found the depths of penetration of X-rays from a cobalt source into films of iron, copper, and aluminium of measured thickness. The results were more than twice as large as those of Schaaber. A formula for the depth of penetration is given, for any metal and any wavelength.
N. MCE.

A High Temperature X-Ray Diffraction Camera. H. J. Goldschmidt and J. Cunningham. (Journal of Scientific Instruments, 1950, vol. 27, July, pp. 177–182). The design of a 19-cm. X-ray diffraction camera, which will operate at up to 1400° C. and embodies features that are desirable for industrial research, is described. The specimen can be in either a vacuum or a gaseous atmosphere, the attainment of a high degree of vacuum being a major consideration. The furnace chamber consists of two platinum shells $1\frac{1}{2}$ in. in dia., wound internally with platinum–rhodium wire (13% Rh); the X-ray gap between the furnace halves is $\frac{5}{16}$ in. The temperature is measured by a movable thermocouple and the pressure by an ionization gauge. For the study of continuous reactions, two cassettes are located outside the vacuum chamber and are designed to record Bragg reflections up to an angular range of 86°. The camera may be used for any type of solid substance, wires or fibres being preferable. The experimental photographic results given show extreme clarity.—H. D. W.

Transformation Behaviour and Temper Stability of Steels Containing Carbide Formers, as Exemplified by a Vanadium Steel. F. Wever, A. Rose, and W. Peter. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Nov.–Dec., pp. 367–379). The transformation behaviour of a steel containing 0·37% C and 2·2% V is described. The ratio C/V is such as to form V_4C_3. Above 1150° C., the steel is austenitic and transformation on slow cooling begins at 950° C. with a carbide precipitation. There follows a γ–α transformation. The pre-eutectoid carbide precipitation is repressed at even very slow cooling rates; the transformation then takes place pseudo-eutectoidally, in a manner similar to pearlite formation in unalloyed steel, in a temperature range down to 550° C. The precipitated V_4C_3 is always comparatively fine; as a result of isothermal transformation at the lower limit of this range it is so fine that when isolated by the Klinger-Koch procedure it shows colloidal properties. This fine-grained V_4C_3 induces pronounced precipitation hardening, the hardness (600 Vickers) being as high as that of the martensitic steel. In the range from 500° C. to the martensite point at 370° C. and below, the steel exhibits an intermediate transformation. Isothermal transformation in this region produces only cementite along with ferrite, the amount of cementite increasing with decreasing transformation temperature. The transformation is always incomplete and the more so the higher the temperature. During the transformation the austenite is enriched in carbon, the enrichment being greater the higher the temperature. This increases the lattice constant, lowers the martensite point and renders the austenite so stable that considerable quantities remain as residual austenite on cooling. Tempering martensitic samples at all temperatures in the intermediate range produces precipitation of cementite. Only by tempering in the pearlite range above 500° C. is V_4C_3 produced. Isothermally transformed and martensitic hardened and tempered specimens do not differ in their carbide phases. Carbon enrichment of austenite during isothermal transformation in the intermediate stage has also been detected in chromium–manganese and manganese–silicon steels.—J. P.

Transformation of Iron and Its Alloys. E. Houdremont. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Nov.–Dec., pp. 413–422). The subject of transformation is reviewed at length. After a discussion of the influence of atomic radius and electronic structure (particularly of the outer d and s orbitals) of alloying elements, transformations in the pearlite and intermediate ranges are considered. There follows a treatment of single-phase separation (Preston-Guinier zones) and the effects of segregation and grain-boundary phenomena.

The Kinetics of the Transformation of Steels. The Composition of the Reactants during the Transformation of a Chromium–Manganese Steel in the Pearlite Range. F. Wever and W. Koch. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, May–June, pp. 143–152: Iron and Steel Institute, 1950, Translation Series, No. 411). This is the first investigation in which the method, devised by Klinger and Koch, for the isolation of carbides has been employed to study transformation kinetics. Tests on a commercial chromium–manganese steel (0·88% C, 0·27% Si, 1·05% Mn, 4·81% Cr) have shown that during transformation in the pearlite range carbides with very different chromium and manganese contents and of two different crystal structures are formed. At temperatures above that of the maximum transformation rate, the carbides have a high chromium content and possess the structure of Cr_7C_3. At the temperature of maximum transformation rate there is first formed a carbide of low chromium content with a structure of Fe_3C, which, only after long holding, takes up chromium and transforms to the stable Cr_7C_3. These processes indicate that the chemical mechanism of the transformation is a chain reaction, the controlling steps of which have different temperature coefficients.—J. P.

The Modern Conception of the Transformation of Austenite. L. Pottecher. (Boletin de Informacion del Instituto de la Soldadura, 1950, No. 6, pp. 22–32). [In Spanish]. The author defines isothermal transformation, austenitizing, and **S**-curves, and explains the various methods of obtaining these curves. The **S**-curve for a eutectoid steel is reviewed, and the upper (pearlite–sorbite–troostite) zone, the intermediate (upper and lower bainite) zone, and the lower martensitic zone are described.—R. S.

Phase Diagram and Phase Transformations in the Iron–Nitrogen System. I. E. Kontorovich and A. A. Sovalova. (Izvestia Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk, 1949, Nov., pp. 1675–1684). Specimens of soft iron were treated in nitrogen at different temperatures and some cooled rapidly and others slowly. Their metastable and stable structures were examined under the microscope and by X-ray methods. The marked change in the quantity of nitrogen absorbed at 650° C. is associated with a second-phase transformation. This transformation is not accompanied by decomposition of the γ' phase. Several phase diagrams of the iron–nitrogen system have been proposed; the present authors find the diagram with the eutectoid transformation to be correct. There is no visible change in the microstructure of nitrogen-bearing martensite after tempering at 150° C., but tempering at 250° C. causes considerable decomposition, and at 350° C. austenite and martensite, both containing nitrogen, break down.—R. A. R.

The System Iron/Iron-Phosphide/Copper-Phosphide/Copper. R. Vogel and J. Berak. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Sept.–Oct., pp. 327–336). The phase diagram of the system Fe–Fe_3P–Cu_3P–Cu has been worked out from thermal and microscopical studies. At equilibrium there are three constituent phases, Fe–Fe_3P–Cu, Fe_3P–Fe_2P–Cu, and Fe_2P–Cu_3P–Cu. The system is characterized by an extensive closed miscibility gap in the liquid state with two upper critical points. Small additions of phosphorus to iron-containing copper produce immiscibility. The tendency of Fe–P alloys to undercool and produce unstable structures is observed also in the ternary alloys with copper, in contrast with those with other elements such as carbon or nickel, which neutralize any such tendency. Also in the Fe–P system, stable equilibria are obtained by rapid cooling and unstable conditions by slow cooling. The formation of two layers is confined to the concentration range of the miscibility gap.
J. P.

The Transformations $\alpha \rightarrow \gamma$ and $\gamma \rightarrow \alpha$ in Iron-Rich Binary Iron–Nickel Alloys. N. P. Allen and C. C. Earley. (Journal of The Iron and Steel Institute, 1950, vol. 166, Dec., pp. 281–288). The work described in this paper has been carried out to determine the effect of nickel on the rate and mode of the transformation in iron–nickel alloys. It forms part of a wider study of the effect of nickel on the transformations in iron. On cooling iron–nickel alloys, the γ-solid solution transforms to a supersaturated α-solid solution α_2. During reheating this solid solution decomposes and the isothermal transformation has been followed dilatometrically and microscopically. The reaction has proved to be complex with two different types of phase change occurring. During isothermal transformation of alloys within the duplex $\alpha + \gamma$ field, the supersaturated solid solution α_2 decomposes into two other solid solutions of different nickel contents whereas, at similar temperatures, alloys initially in the γ-phase show no evidence of transforming isothermally $\gamma \rightarrow \alpha$. The kinetics of the slow isothermal transformation $\alpha \rightarrow \gamma$ are briefly discussed.

Sigma-Phase in the Co–Cr and Fe–Cr Systems. G. J. Dickins, Audrey M. B. Douglas, and W. H. Taylor. (Journal of The Iron and Steel Institute, 1951, vol. 167, Jan., p. 27). Several iron–chromium alloys of composition near 50 at.-% Cr and cobalt–chromium alloys have been studied by X-ray methods. The density of σ-FeCr was found to be 7·625 g./c.c., so that this cell contains 30 atoms. Results obtained by C. W. Tucker, jun. for a W–Cr alloy containing 1·4 at.-% Cr are cited ; this structure is tetragonal ; the dimensions of the unit cell (which contains 30 atoms) correspond closely with those of σ-FeCr, and the possible space groups are the same. The β-uranium structure is said to be hard and brittle—properties which are also characteristic of the σ-phase. It seems extremely probable that the σ-structure is essentially that proposed by Tucker for β-uranium.—B. A. R.

Determination of Equilibrium Diagrams by Means of Electric Resistance Measurements. H. Vosskühler. (Metall, 1950, vol. 4, June, pp. 231–235). The author describes and discusses the electric resistance technique of determining equilibrium diagrams. He recommends the use of conductivity isotherms and resistance *v.* temperature curves. When phase boundaries run parallel to the temperature axis, they show up clearly on the isotherms, but not at all on the resistances *v.* temperature curves. The converse is true of phase boundaries parallel to the composition axis. Isotherms are preferable in the case of measurements carried out when heating previously annealed specimens. Resistance measurements at the equilibrium temperature are recommended when the temperature of reactions, in which the resistivity rises suddenly, is to be determined ; bar specimens are to be preferred to wires. Equilibrium at low temperatures is reached more quickly by annealing homogenized alloys at the equilibrium temperature, than by cooling down to it.

J. G. W.

A Note on Silicon Distribution between Austenite and Liquid Metal in Freezing Hypo-Eutectic Cast Iron. A. Hultgren and O. Carlsson. (Journal of The Iron and Steel Institute, 1950, vol. 166, Dec., pp. 303–304). The silicon distribution between austenite and liquid metal during the freezing of cast iron, as shown in the iron–silicon–carbon equilibrium diagram of Jass, is qualitatively confirmed. Sampling is carried out using a graphite tube, and the assumption is made that no graphite eutectic is formed.

The Carbide Phase in Iron–Carbon–Silicon Alloys. W. S. Owen. (Journal of The Iron and Steel Institute, 1951, vol. 167, Feb., pp. 117–120). The dimensions of the unit cell of the crystal structure of the carbide phase extracted from a plain carbon steel, a commercial white iron, a high-purity, vacuum-melted iron–carbon–silicon alloy, and a similar alloy melted in air, have been measured to a high degree of accuracy by a Debye-Scherrer powder X-ray method. No variation in the dimensions of the cell has been found. It is concluded that silicon in iron–carbon–silicon alloys does not enter the carbide phase, and from this it is deduced that the position commonly accepted for the peritecto-eutectic point in the metastable diagram of this ternary system is probably considerably in error.

ANALYSIS

Modern Trends in Spectroscopy. A. C. Menzies. (Journal of the Royal Society of Arts, 1951, vol. 99, Feb. 23, pp. 283–302). The author classifies spectra into 'continuous spectra,' 'line spectra,' and 'band spectra.' A second classification is emission or absorption spectra ; the former are characteristic of sources, and the latter are characteristic of materials. A third classification is according to the wavelength region being investigated. The chief use of emission spectra is in the analysis of metals. A modern grating spectrograph for the visible and ultra-violet regions employs a concave grating. If only a particular region of the spectrum in a certain order is wanted, the light proceeding in other directions is wasted. This confers a 'blaze' on the grating ; the grating is referred to as an 'echelette.' In consequence of the development of the multiplier photocell, 'direct readers' have been made by two firms in the United States. A glowing filament and a hydrogen arc provide sources of continuous spectrum for the visible and ultra-violet regions respectively. The light is dispersed by prism monochromator and then passes through a cell containing the absorbing solution under test and finally falls on the cathode of the photocell. In series with the photocell is a resistance across which a potential difference is set up by the photocurrent. A recent development has been the use of devices for polarizing the incident radiation in infra-red instruments. This is of use in studying the molecular structure. The author gives a brief description of the Raman effect with some illustrations. In the region of microwaves measured in centimetres and millimetres, spectroscopy is principally concerned with the measurement of the absorption of radiation by gases at low pressures. For the recording of X-ray emission and absorption spectra, older methods have now been supplemented by Geiger-Müller tube techniques. The chief advantage of the Geiger-Müller tube technique is that an analysis can be carried out quickly and automatically, once the spectrometer has been set up and put into motion. The most important recent trend is towards greater use of electronics in the development of spectrometers.—E. T. T.

Principles and Choice of Methods of Spectro-Chemical Emission Analysis Applied to Metallurgy. R. Castro. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1950, vol. 47, July, pp. 521–527). This survey covers: Spark and continuous arc generators ; types of electrode employed for conducting and non-conducting material, solid or divided ; the production of spectra by prisms or diffraction gratings ; and the reception of spectra by eye, photocell, or photographic plate. Methods of analysing alloys from spectra are discussed.

A. G.

Equipment Used in Spectrochemistry. M. P. Coheur. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1950, July, pp. 531–543). A survey with photographs of equipment (mainly American) including spark and arc generators, spectrographs, plate viewers, and densitometers is presented. Apparatus for direct analysis in industry is also shown.—A. G.

Elimination of Errors Due to Variations in Background in Quantitative Spectrography. E. Roux and C. Husson. (Comptes Rendus, 1950, vol. 231, Oct. 16, pp. 770–772). A standard photographic plate is made having a continuous background equivalent to that due to the impurities in the substance analysed. From this, calibration curves are plotted enabling the quantity of the constituent to be read off directly.—A. G.

A Statistical Study of the Behaviour of Spectrographic Source Units. H. T. Shirley, A. Oldfield, and H. Kitchen. (Journal of The Iron and Steel Institute, 1950, vol. 166, Dec., pp. 329–338). Following up previous work on the statistical examination of the magnitude and origin of variability in spectrographic analysis of low-alloy steel, the authors have carried out a more detailed study of the influence of factors operative during excitation. The work includes a comparison of various types of excitation unit, particularly of the ordinary uncontrolled Hilger high-voltage condensed spark unit and the Metro-Vickers controlled low-voltage source. Over 30,000 readings from more than 15,000 lines have been used. The results have permitted the selection of certain optimum conditions within the range of variables studied, and have shown that the most favourable results are obtained with the simple Hilger unit, operating with a graphite auxiliary electrode and a 2½-mm. gap. The use of air blast across the gap, the inclusion of a 15-sec. pre-spark period, or variation in the length of exposure over a wide range, showed no important effects on this reproducibility. In addition to the main series of tests with the Metro-Vickers low-voltage source, the work with controlled units has included the use of a Metro-Vickers high-voltage unit, a multi-source low-voltage unit, and a B.N.F.M.R.A. (British Non-Ferrous Metals Research Association) low-voltage unit. It is shown that under the optimum conditions tested, these controlled sources can give results approaching those of the simple Hilger unit for suitably matched line-pairs. The divergence tends to be much greater for less favourable line-pairs and extremely high variability may be found.

Spectrochemical Analysis of Steelmaking Slags. C. G. Carlsson and J. T. M. Yü. (Journal of The Iron and Steel Institute, 1950, vol. 166, Dec., pp. 273–280). A procedure is described for the determination of lime/silica ratio of open-hearth and electric-furnace slags and for the complete analysis of such slags. The sample is mixed with graphite powder and pressed into a briquette, which is subjected to a low-tension arc-like triggered spark for excitation. The actual percentages of the oxides are calculated using a 'mutual

standard method.' The accuracy compares favourably with routine chemical analysis, and the time necessary for a complete analysis is only about half an hour. Complete details of the method are given.

Spectrographic Research for Traces of Elements. A. Gatterer. (Metallurgia Italiana, 1950, vol. 42, July, pp. 244–248). Amongst the various physicochemical methods for tracing minute quantities of secondary elements in a basically pure element, the most effective and more generally adopted is the spectrochemical method. This, it is suggested, will continue to remain the best method for many years to come. In order to apply the method efficiently, it is necessary to know the fundamental principles on which it is based as well as the practical results which may be derived. This paper gives a clear explanation of the fundamental principles of the method and then deals with its application : (1) to the preparation of the sample ; (2) to the preparation of the spectrographic apparatus ; (3) to the photographic process ; and (4) to the reading and interpretation of the plates in order that the spectrum lines may be rapidly and surely identified.—M. D. J. B.

Rapid Determination of Phosphorus in Steels. A. Hans. (Journal of The Iron and Steel Institute, 1950, vol. 166, Oct., pp. 118–122). Following a short outline of the methods of Hanau and Wolfe and of Hasler and Barley, for the spectrographic analysis of steel, the results of a number of comparative experiments made with these methods are given. These experiments induced the author to study two types of receiver, namely, the Geiger-Müller counter and the electron multiplier tube, and to compare their respective values for use in the estimation of phosphorus. These researches bore also upon the conditions of excitation, and the one definitely favoured is a special arc-discharge, which markedly weakens the line in the neighbourhood of the 2149 P line. The standard deviation is about 2·5% and the analysis time is about 50 sec.

Spectrographic Analysis in the Grey Iron Foundry. E. J. Ronnie and M. M. Hallett. (Institute of British Foundrymen : Foundry Trade Journal, 1950, vol. 89, Aug. 3, pp. 115–123). The spectrographic determination of all elements except carbon, sulphur, and phosphorus, in both low-alloy and high-alloy irons of the austenitic and 33% chromium types is possible. The test piece advocated, the laboratory layout, the method of ensuring a constant laboratory temperature, and the organization of the laboratory are described. Using the Argyl and Price method of plate calibration, the standardization of plate processing is not so critical and graphs, once constructed, can be used indefinitely. The routine analysis of high alloy and pig irons is outlined, and the method of estimating the magnesium content in nodular cast irons is detailed.—J. E. W.

Recent Applications of Infra-Red Spectra. L. Bologna. (La Chimica e l'Industria, 1950, vol. 32, Aug., pp. 380–387). [In Italian]. A brief review is given of the historical development of infra-red spectrographic analysis as an experimental method. The field of application to chemical research is discussed. The fundamental principles are described as well as the apparatus, the measurement of wavelengths, and the preparation of samples for testing. Practical applications are also considered with reference to both qualitative and quantitative analysis.—M. D. J. B.

The True Value of the Methods for Analysis of Gases in Steels. F. Meunier. (Revue Universelle des Mines, 1950, Series 9, vol. 6, Aug., pp. 246–255). After explaining the importance of the accurate determination of gases in steels, the author critically surveys the methods in use today. The technique of Kempf and Abresch, which is a modification of the Kjeldahl method, is recommended as being the most simple and accurate one for the determination of nitrogen. The methods of C. H. Hertz, jun., and A. Gotta are the most suitable for the determination of oxygen in liquid and solid steel respectively. In contrast with the estimation of nitrogen and oxygen, the accurate analysis of hydrogen involves the use of high-frequency induction heating *in vacuo* which is not suitable for works routine analyses. This difficulty is discussed.—B. G. B.

The Evolution of Gas—From Pig Iron to the Finished Products. J. Massinon. (Revue Universelle des Mines, 1950, Series 9, vol. 6, Aug., pp. 255–266). After consideration of the methods currently available for the determination of nitrogen in steels and the errors which accompany them, the author describes a method which distinguishes between two nitrides in cast iron, the more important being silicon nitride. Investigation of pig iron shows that the phosphorus and carbon concentrations appear to affect the nitrogen content. There is no evidence that the concentration of silicon or the blast-furnace conditions have any effect. Operations subsequent to tapping are able to vary the total nitrogen content and the form of combination. A description of a method for the classification of nitrogen dissolved in steel into three categories is given. Experiments on a basic-Bessemer converter have shown that the nitrogen content reaches a minimum value towards the end of the carburization period. Special study of the oxygen and nitrogen concentrations during dephosphorization using oxygen-enriched blast has also been carried out and the results are given.—B. G. B.

Instrumental Methods of Analysis Other than Spectrography. G. Charlot. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1950, vol. 47, July, pp. 528–530). A brief account is given of the principles, accuracy, and scope of spectro-colorimetry, polarography, amperometry (the measurement of current during titration) and potentiometry, many automatic instruments being available. Spectrochemical methods for the determination of chromium and manganese and also of traces of nickel are described in some detail. Potentiometric methods have little advantage when a good indicator exists, but rapid electrolysis at controlled potential is useful, *e.g.*, for the determination of iron in the presence of aluminium, boron, etc., using a mercury cathode.—A. G.

Notes on the Rapid Determination of Sulphur in Steel by the Planochromatic Method According to Glazunov and Jirkovský. J. Korecký and J. Nejedlý. (Hutnické Listy, 1950, vol. 5, Sept., pp. 359–362). [In Czech]. The authors find that if samples from cast specimens are used to determine sulphur by the method of Glazunov and Jirkovský the evolution of H_2S is intermittent and that the results obtained are influenced by the temperature and concentration of the acid, and to a less extent by the surface condition and heat-treatment of the specimen.—E. G.

The Application of Perchloric Acid to the Analysis of Steelworks Materials. G. Croall. (Metallurgia, 1950, vol. 42, July, pp. 99–104). The extensive uses to which a 70% solution of perchloric acid can be put in steelworks analytical laboratories is described. In this form the acid is no more dangerous than concentrated sulphuric acid, and dangers from bringing it into contact with organic materials can be overcome by previous treatment of the material with nitric acid. Its uses include the initial decomposition of materials such as chrome brick samples, firebrick samples, calcium silico-manganese alloys, and many other difficult materials. Its use is described in the estimation of chromium volumetrically, chromium, manganese, molybdenum, and nickel colorimetrically, and of niobium, titanium, tungsten, aluminium, potassium, phosphorus, and sulphur. The author claims that this reagent saves both time and labour in the routine laboratory work and deserves more widespread use.

Determination of Cementite and Dissolved Carbon in Heat-Treated Carbon Steels. (Hutnik, 1950, vol. 17, July–Aug., Biuletyn Glownego Instytutu Metalurgii i Odlewnictwa, pp. 19–21). [In Polish]. A sample of steel is electrolytically dissolved in sodium chloride solution acidified with citric acid (pH 5·5–7) at current density of 0·02 amp./sq. cm. at a temperature 2–5° C. in 10–17 hr. The sponge-like residue obtained is transferred into sodium sulphite solution and washed by centrifuging. The washed residue is dissolved in boiling hydrochloric acid. Undissolved amorphous carbon is filtered off and determined by combustion. The iron in the filtrate is determined, and the percentage of cementite in the steel is calculated from this.—V. G.

The Accurate Determination of Carbon in Low-Carbon Steels. J. E. Wells. (Journal of The Iron and Steel Institute, 1950, vol. 166, Oct., pp. 113–117). An apparatus for the accurate determination of carbon in low-carbon steels is described. The method is based on the use of a liquid-oxygen trap for the isolation of carbon dioxide produced by burning the steel in oxygen. The quantity of carbon dioxide formed is subsequently estimated by measuring the pressure exerted when it is confined to a known volume. The apparatus gives reproducible results of at least the same order of accuracy as those obtained by other low-pressure methods, and has the merit of simplicity. A combination of one combustion unit with two liquid-oxygen traps enables one carbon determination to be completed every twenty minutes. The method can

also be used for the micro-determination of carbon, using sample weights of 0·02 g.

Determination of Phosphorus in Alloys. J. L. Kassner and Mary A. Ozier. (Analytical Chemistry, 1950, vol. 22, Sept., pp. 1216–1217). The usefulness of the authors' double-strength citromolybdate solution, which permits rapid precipitation of ammonium phosphomolybdate from a boiling solution, has been extended to include the determination of phosphorus in steels (whether soluble or insoluble in nitric acid), cast iron, ferrophosphorus, and phosphor-bronze. Details and results of these analyses, which include a volumetric finish, are given.—J. B. B.

The Determination of Small Amounts of Aluminium in Iron. H. G. Short. (Analyst, 1950, vol. 75, Aug., pp. 420–425). The determination of aluminium in iron in amounts down to 0·001%, with an accuracy of ± 0·0005% is described. Iron and other interfering elements are separated by an ether separation, followed by chloroform extraction of cupferron complexes at *p*H 0·5. Aluminium is determined in the resulting aqueous layer by means of 'aluminon.' It is suggested that the method could be extended to metals other than iron by including a second cupferron separation at *p*H 3·5, when aluminium alone is extracted.—J. B. B.

The Use of Gelatin in the Determination of Silicon in Ferrous Alloys, Especially Silicon-Rich Ferro-Alloys. M. H. Jenkins and J. A. V. Webb. (Analyst, 1950, vol. 75, Sept., pp. 481–485). The precipitation of silica by means of gelatin and its application to silicon determinations on high-silicon alloys is discussed. Two methods have been devised. One involves the boiling of a sulphuric-acid extract of the melt; it gives results that are low, though possibly suitable for works measurements. The other involves a dehydration procedure before the precipitation of silica by gelatin; it is as rapid as the first method and capable of giving a high degree of accuracy.—J. B. B.

The Analysis of Inclusions. M. Lacomble. (Revue Universelle des Mines, 1950, Series 9, vol. 6, Aug., pp. 264–269). A survey of the normal methods available for the separation of inclusions in steel is made. Details are given of an electrolytic method in which the sample of steel is made the anode in an electrolytic cell with a mercury cathode and an electrolyte consisting of a solution of sodium chloride, potassium bromide, and sodium citrate. The shape of the sample is arranged so as to have a large surface area. Using 20–25 amp. at 10 V. approximately 20 g. of steel can be dissolved in 45 min. The results obtained are compared with the standard iodine extraction method.—B. G. B.

Some Definitions Necessary for the Interpretation of Coal Analyses. J. François. (Chaleur et Industrie, 1950, vol. 31, Dec., pp. 301–305). Standardization of nomenclature used in the assay of combustible solids is of practical and commercial importance, and some definitions are proposed. Moisture is associated with coal in two forms, 'free moisture' and 'bound moisture.' Ash can be defined as 'the mineral matter left after burning off the combustibles,' but it must be remembered that some original mineral matter is lost through decomposition on combustion, and that some ash arises from the fixing of organic sulphur. Pure coal C_p, can be expressed as $C_p = C_b \cdot \frac{100 - H}{100} \cdot \frac{100 - A}{100}$, where C_b is crude coal, H is total moisture, and A is total original mineral matter. Also defined are crude coal, air-dried coal, desiccated coal, total carbon, fixed carbon, total sulphur, combustible sulphur, and total nitrogen. Swelling, coking, and agglutination are mentioned, and calorific values (gross and net) are discussed.—T. E. D.

Recent Developments in Gas Analysis with Special Reference to Fuel Gases. M. P. Mendoza. (British Coal Utilisation Research Association, 1950, vol. 14, Nov., pp. 409–419). The author reviews developments in methods of analysing mixed gas, particularly the determination of selected constituents of fuel and waste gases. There are 103 references.

R. A. R.

The Rapid Determination of the Forms of Sulphur in Coal. R. A. Mott. (Fuel, 1950, vol. 29, Mar., pp. 53–61). The determinations of the three forms of sulphur (sulphate, pyritic, and organic) in coal are considered. The present standard methods for sulphate and pyritic sulphur require digestion for 40 and 24 hr. respectively, in dilute HCl and dilute HNO_3 at 60° C. and at air temperature. The present proposals reduce the digestion to 30 min. for each acid, which is boiled. These methods, arrived at under standardized conditions, ensure that the HCl will not attack pyrites and the HNO_3 will not attack the organic sulphur.—R. A. R.

The Determination of Moisture in Coal. E. G. Barber. (Journal of the Institute of Fuel, 1950, vol. 23, Nov., pp. 295–296). Methods for the determination of the 'inherent' or 'air-dried' moisture content are surveyed. The methods are classified as indirect, direct, and those based on the physical and chemical properties of water. The indirect methods involve measuring the loss in weight of the sample, and the direct methods involve the collection and weighing by weight or volume of the water. The methods for determining total moisture are discussed. It is suggested that duplicate sampling is probably desirable and the use of sub-samples and control charts is a necessary adjunct to a proper appraisal of the moisture content.—J. P. S.

A New Method for the Titrimetric Determination of Sulphur in Coal. R. Belcher and C. E. Spooner. (Fuel, 1950, vol. 29, Aug., pp. 188–189). The rapid method for the simultaneous determination of carbon, hydrogen, sulphur, and chlorine in coal has been modified. Carbon and hydrogen are determined as in the original method, but sulphur is got by titrating the silver sulphate extracted from the silver gauze with standard potassium thiocyanide solution. This modification enables a series of coals to be analysed rapidly, whereas in the original method the time between combustions was prolonged owing to the necessity of waiting for the spiral to cool. An attempt has been made to improve the qualitative and quantitative accuracy of the chlorine determination, and a turbidimetric method was investigated. This method gave results as accurate as the British Standard method but it is time-consuming, hence the determination of chlorine is no longer recommended by this procedure; however, the chlorine figure is rarely required and the main elements carbon, hydrogen, and sulphur can be determined rapidly and conveniently by a single combustion.—J. P. S.

An Absorptiometric Method for the Determination of Phosphorus in Coal and Coke Ash. R. Belcher. (Fuel, 1950, vol. 29, Oct., pp. 232–235). A method for the determination of phosphorus in coal and coke ash which occupies less than 2 hr. is described. Phosphorus is extracted from the ash by the procedure described in British Standard 1016 except that smaller amounts of ash and acid are used. The phosphorus is finally determined by the development of molybdenum blue, the colour intensity of which is measured in a Spekker absorptiometer. Only 50 mg. of ash are used regardless of the phosphorus content, hence it is unnecessary to carry out a preliminary determination when the phosphorus content is unknown.—J. P. S.

Rapid Determination of Chlorine in Coal by Ignition Using Eschka Mixture. (Fourth Report of Panel No. 1, British Coke Research Association, Nov., 1950). An account is given of the work carried out during the last four years to develop a method for the rapid determination of total chlorine in coal and coke. It was possible to reduce the period of incineration at 475° C. from 20–24 hr. to 4 hr. for 5 g. of coal by employing the well-ventilated muffle standardized for the determination of total sulphur in coal. Although a further reduction in the time of the incineration by: (*a*) Using 1 or 2 g. of coal, and (*b*) increasing the temperature of incineration, gave promising results, the variation in the results was too great to justify general recommendation. In the course of these tests the temperature of incineration had been increased to various temperatures up to 600° C. The solution was eventually found by increasing the temperature to 775° C. ± 25° C. and reducing the weight of sample to 1 or 2 g. Contrary to expectation, the loss of chlorine by incineration at this high temperature does not occur, whilst the use of 1 g. of coal enables the final Volhard titration with silver nitrate to be made without filtration. Thus a test can be completed in under 1½ hr. using the muffle temperature and conditions recommended for the determination of ash. The final method is therefore rapid, easy to carry out, and sufficiently accurate for routine operations.—P. C. P.

INDUSTRIAL USES AND APPLICATIONS

Electronics Applied to Engineering. S. H. Dale. (Proceedings of the South Wales Institute of Engineers, 1950, vol. 66, Sept., pp. 18–43). This paper is confined to the application

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of electronic control systems to the automatic control of voltage, current, power, position, velocity, and acceleration. Basic control principles of self-regulating systems are outlined and the effect of time lags is discussed. It is shown that accuracy and speed of response can be high, and examples are given of a few practical systems.—H. R. M.

Wire Ropes in Mines: Some Impressions of the Ashorne Hill Conference. M. A. Hogan. (Iron and Coal Trades Review, 1950, vol. 161, Sept. 29, pp. 519–520). The author describes some of the outstanding points of interest at the Conference on Wire Ropes in Mines, held in Sept. 1950 and sponsored by the Institution of Mining and Metallurgy. The relative merits of acid and basic steel for wire-making were discussed, and much interest shown in the application of ultra-high-strength wire. Considerable discussion of safety factors took place, and British and Continental practices were compared in this respect. Continental installations of Koepe hoists and the different types of capel attaching the rope to the load were described, and many drawbacks encountered in the use of safety catches were pointed out. The high degree of skill and reliability required in rope examination was stressed.—G. F.

Alloy Steels and Their Uses. (British Iron and Steel Federation Monthly Statistical Bulletin, 1950, vol. 25, Sept.–Oct., pp. 1–9). Alloy steel is defined as steel containing not less than 0·40% Cr or Ni, or 0·10% Mo or W or V, or 10% Mn. When cobalt, niobium, or titanium are incorporated, it is usually in conjunction with one or more of the above elements. At its peak, production reached 1,595,600 tons for the year 1943 while in 1949 it was 767,700 tons. Data on production by districts, deliveries to different industries, and the uses and sources of many alloying elements are given.—E. C. S.

Stainless Steel Trains for New York Subways. (Engineer, 1950, vol. 190, Dec. 29, p. 651). An illustrated description is given of the new stainless trains for the New York subways. Each vehicle weighs 37 tons, seats 54, and is 60 ft. long × 10 ft. wide × 12 ft. high.—R. A. R.

Seamless Tubes—An Opportunity Lost by Brazil. B. C. de Mattos Netto. (Mineração e Metallurgia, 1950, vol. 15, May–June, pp. 23–24). [In Portuguese]. At the outbreak of war in 1939 the great Hungarian organization of Manfred Weiss of Budapest intended to move to Brazil. It was to produce 600 tons of seamless tubes per month, based on Brazilian electric pig iron. The properties and applications of such tubes are discussed. The formulæ for determining stresses in boiler tubes are given.—R. S.

HISTORICAL

Commemoration of the Centenary of the Birth of Sidney Gilchrist Thomas, 1850–1885. (Revue de Métallurgie, 1950, vol. 47, Dec., pp. 3–22). Ceremonies lasting two days took place at Esch-sur-Alzette, Luxemburg, on April 15 and 16, 1950, to honour the memory of Sidney Gilchrist Thomas, at which the following addresses were presented:

The Life of S. G. Thomas (1850–1885), by C. H. Desch, F.R.S.

The Basic-Bessemer Process in French Inheritance, by M. Allard.

The Economic Consequences of the Invention of Sydney Gilchrist Thomas, by A. Aron.

Creators of the Steel Age: Sir Henry Bessemer, F.R.S. R. Edwards. (British Steelmaker, 1951, vol. 17, Jan., pp. 30–40). This article is a short biography of the life of Sir Henry Bessemer, F.R.S. The author describes the history of the Bessemer steelmaking process from its initial failure to its eventual adoption by the steel industry and its recognition as one of the most notable metallurgical discoveries of all time. Whilst dealing chiefly with this process, the author also indicates Bessemer's versatility in other fields, and states that at that time he had no superior in either the number or ingenuity of his inventions.—G. F.

The Hadfields of Sheffield. S. A. Main. (Bulletin of the Institution of Metallurgists, 1950, vol. 2, Dec., pp. 21–26). The story of the foundation of Hadfields, Ltd., by Robert Hadfield in 1870 is told. The founder's pioneering work on the manufacture of steel castings and armour-piercing projectiles, followed by his son's, Sir Robert A. Hadfield, discovery of manganese steel and silicon steel, and the subsequent development of the steelworks up to the present day, are described.—J. W. P.

The Development of Wire Rod Production from the 17th Century to the Present Day. L. Thomas. (Wire Industry, 1950, vol. 17, Sept., pp. 737–743; Oct., pp. 823–827).

ECONOMICS AND STATISTICS

Description and Analysis of Manufacturing Processes. I. Echaide Itarte. (Anales de Mecanica y Electricidad, 1950, vol. 26, Mar.–Apr., pp. 67–80; May–June, pp. 157–162). [In Spanish]. The author analyses manufacturing processes and seeks to simplify them to improve the science of movements. The necessary data for a detailed description of distinct stages of manufacture are examined. These can be classified as: Operation, transport, inspection, dispatch, and storage. The Gilbreth symbols for the division of processes, and the Piacitelli signs for process diagrams are illustrated. Finally, practical examples of the simplification of manufacturing processes are given. These include the ordering of raw materials, the reconditioning of buffing wheels, and the assembly of water meters.—R. S.

The Sources and Nature of Statistical Information in Special Fields of Statistics—Statistics Relating to the U.K. Iron and Steel Industry. R. M. Shone. (Journal of the Royal Statistical Society, Series A, 1950, vol. 113, Part 4, pp. 464–486).

Statistics of Stoppages as a Component of Industrial Statistics. K. E. Poppe. (Stahl und Eisen, 1950, vol. 70, Aug. 31, pp. 774–784). In compiling statistics for the control of industrial processes, special attention should be paid to stoppages and slowing down of machines, etc. Schemes are presented by which such observations may be recorded in a manner which allows their effects on output and cost to be assessed.—J. P.

Productivity Measurements in British Industry. (Anglo-American Council on Productivity, Nov., 1950). This 'Productivity Report' contains six papers presented at a Symposium which show how productivity measurements are taken in order to make comparisons, and describe how the difficulties of making comparisons where products differ have been overcome. The assessment of progress by indices at the works of Joseph Lucas, Ltd., is described. A. W. Swan describes how a shift report is prepared at the rolling mills of The United Steel Companies, Ltd., and how it is corrected for different rolling rates, different types of product, and stoppages.—R. A. R.

The Interdependence of the European Iron and Steel Industries. (British Iron and Steel Federation Monthly Statistical Bulletin, 1950, vol. 25, May, pp. 1–10). Europe is largely self-sufficient in coal, scrap, and iron ore but individual countries are in a very different position. France imports coal, while Germany and the U.K. import iron ore. Belgium, the Netherlands, and the Saar have no iron ore, whilst Luxembourg, Italy, and Sweden have no coal. The tables of the iron and coal reserves and of inter-European trade (1937 and 1949) in iron ore, coal, and coke are presented.
E. C. S.

Production in the Steel Industry, Its Growth, Distribution and Future Course. Sir Andrew McCance. (Cleveland Scientific and Technical Institution, Third Harold Wright Lecture, Nov., 1950). In this lecture the statistics of iron and steel production in the United Kingdom and the U.S.A. since 1868 are analysed in order to determine what factors control the development of the industry. The number of works having a given output is shown to be distributed exponentially, leading to the conclusion that the production of the largest individual unit is related to the total output of the industry. The expression

$$P = P_0 \log\left\{1 + \left(\frac{D}{D_0}\right)^2\right\}$$

where P = daily production in tons and D = hearth diameter, P_0 and D_0 being constants, is given as showing the relation between the hearth diameter and output of a blast-furnace. The difficulties involved in building and operating a blast-furnace of 2000 tons/day output are discussed. The annual production from a particular type of furnace is shown to be proportional to the square of the number of furnaces, alternatively, to the square of their average capacity. The proportion of the total number of furnaces less than a given capacity is plotted against the capacity squared, and this curve approximates closely to the normal probability integral.

Dealing with the growth and decline of steel production the equation

$$A.\frac{d^2Q}{dt^2} + B.\frac{dQ}{dt} = C.Q$$

is developed relating the production Q with time t (A, B, and C are constants). Particular solutions of this equation are given for acid-Bessemer steel production and the production of Britain and the United States of America since 1868. These curves fit the statistical data well, and are used to predict the future steel production in the United Kingdom. An examination of the variations in demand, as shown by deviations from the theoretical curve of the growth of production, reveal that the actual rate has coincided with the normal rate every nine to nine and a half years consistently over the past 60 years.—J. W. P.

The Proposed New England Steel Plant. C. S. Strike. (Iron and Steel Engineer, 1950, vol. 27, Nov., pp. 85–87). In this article the author reviews the reasons for which New England claims the need for an integrated iron and steel plant. Political, social, national, and economic arguments are developed in making the case for the proposed new works.

MISCELLANEOUS

The Rational Performance of Manual Labour. H. Spitzer. (Stahl und Eisen, 1950, vol. 70, June 8, pp. 509–515). In spite of the mechanization of industrial processes there is a growing shortage of heavy manual workers. Manual effort should not be wasted and its performance should be made as congenial as possible. Physiological studies have been made of operations of shovelling, load-carrying, and moving loaded trucks, and it is shown that by attention to the correct design of tools, the correct size of load, distance to be moved, etc., a given amount of work can be accomplished with the expenditure of much less energy than by traditional rule-of-thumb methods.—J. P.

Introductory Manual on the Control of Health Hazards from Radioactive Materials. (Ministry of Supply, Atomic Energy Research Establishment, 1949, Jan., Issue No. 2). This 15-page manual is issued under the authority of the Protection Sub-Committee of the Medical Research Council's Committee on the Medical and Biological Applications of Nuclear Physics.
R. A. R.

How To Find Detailed Information When You Want It. A. H. Geisler. (Metal Progress, 1950, vol. 57, May, pp. 613–617). A new card index system devised by the American Society for Metals and the Special Libraries Association for classifying information on metals is explained. The system is based on punched cards indexed for material, process and property, author, and common variables, and is simple to use.—E. T. L.

Information from the Chemical Equation. C. Locke. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, Dec., 1949, vol. 7, pp. 315–322). Explanations are given of the meaning and use of chemical equations, heat of reaction, equilibrium constant, the law of mass action, activity coefficient, and free energy.—R. A. R.

BOOK NOTICES

COSSLETT, V. E. "*Bibliography of Electron Microscopy.*" 8vo, pp. 350. London, 1950: Edward Arnold. (Price 40*s.*)

Dr. Cosslett, whose work on electron microscopy is well known, has compiled a bibliography of about 2500 entries on the subject; the period most closely covered is the decade before 1948, although there are many pertinent references dated as far back as 1930. This work would be of greater use to the scientific worker in a specialization such as metallurgy if it were indexed according to subject, or even to date, instead of being arranged in alphabetical order of authors. It is no real consolation to know that, for an extra five shillings, one may purchase an edition of the book in folded and collated sheets printed on one side only which may be cut up, mounted, and formed into a card index: specialists, at least, have probably card indexed their own material already. Moreover, the 2500 entries mentioned above include scarcely half that number of abstracts; what there are are usually of good quality and informative, but there is a large residue of interesting matter, not only in foreign-language periodicals, but also on generalized aspects of the subject, which is mentioned solely by title.—J. P. S.

GLOAG, J. "*How to Write Technical Books.*" Illustrated. Small 8vo, pp. x + 160. London, 1950; George Allen & Unwin, Ltd. (Price 12*s.* 6*d.*)

Mr. Gloag's text is "They don't want to read it," and his formula for exposition once "they" have been brought to the point of reading it is a quotation from Hilaire Belloc, "Tell them that you are going to tell them something; then tell them; then tell them you've told them." It is the scientists and technical workers who are forced to read textbooks and papers who are "they" in this context: Mr. Gloag, from considerable experience, believes in simplicity of expression, the avoidance of jargon and *cliché*, and in the careful planning, in advance, of the material to be communicated. He disciplines himself to this approach in this book, so that, on the subjects likely to be of interest to the potential author of a technical book, such as the most satisfactory position for footnotes and references, the choice of type face, the style and arrangement of illustrations, he is lucid and comprehensive. His detailed analysis of a typical contract between author and publisher shows that no one should lose sight of the fact that, while it may be a technical and artistic success, a book may none the less be a financial success for both sides. All this Mr. Gloag tells us—and then tells us that he has told us, according to his rule. It is the more surprising, therefore, that his book concludes with a chapter "The Reform of Forms," of no connection with the previous matter, but containing several examples showing how, by more systematic layout, by linguistic simplification of the questions, and by the use of two- and three-colour printing, it might be made almost a pleasure to fill in an application for a building licence or for the replacement of a lost ration book.—J. P. S.

HUGH-JONES, P., and C. M. FLETCHER. "*The Social Consequences of Pneumoconiosis among Coal Miners in South Wales.*" 8vo, pp. ii + 54. London, 1950: Medical Research Council: H.M. Stationery Office. (Price 1*s.* 9*d.*)

There have been great advances in recent years in the study and prevention of lung diseases in underground workers. The classic researches of Hart and Aslett proved conclusively that 'miners' asthma,' as it was once known, could be caused by coal dust as well as by rock dust, and established the term 'pneumoconiosis' to describe all pulmonary dust diseases in coal miners. Before 1928, this disease, however occasioned, was not compensatable; in that year, however 'silicosis' was recognized, but only on the severest of terms; only men who were totally disabled and were known to have been working in silica rock, could apply for compensation. The stages by which this has been extended to lesser degrees of disablement, and the growth of knowledge which has enabled the earliest stages of pneumoconiosis to be recognized on X-ray photographs are briefly outlined here, and it is a matter for congratulation of all concerned that men no longer have to gasp their lives away because their X-ray plates do not show the standard pictures. The rest of the report is concerned with the after effects of the disease on the men who, on certification, were automatically suspended from work in the mining industry in South Wales; from January 1931 to July 1948, the number was 19,000, of whom 16,000 still survive. Many of these, becoming breathless on physical exertion, and living remote from other centres of industry, failed to find other work: there are still some 5000 unemployed pneumoconiosis cases concentrated in the mining valleys of South Wales, of whom three-quarters are capable of medium or light industrial work. Where these men have found work not entailing strenuous physical exertion their sick and absence rates are no higher than those of normal men, but there is evidence that the disease may progress, even after removal from its cause, the degree varying from man to man, and that other infections, to which the damaged lungs have become susceptible, may supervene. A specific medical need is a follow-up of certified cases; the greatest need, the authors assert, is suitable employment. "Nothing else

can prevent the mental and physical deterioration that so often accompany enforced idleness and also ensure a reasonable standard of living." It is encouraging to note that the question of their employment, at least, is being considered by a number of Government departments whose activities are co-ordinated by the National Joint Pneumoconiosis Committee. The question of the medical follow-up, and regrading according to the degree of disability do not, however, appear to be under consideration.—J. P. S.

KIEFFER, R., and HOTOP, W. "*Fer et Aciers Frittés.*" 8vo, pp. xx + 573. Illustrated. Paris, 1951 : Dunod.

This is a translation by R. Chouteau and R. Meyer, of "Sintereisen und Sinterstahl," a review of which appears in Journ. I. and S.I., 1948, vol. 160, pp. 343–344. In preparing this full French translation the authors have brought the references up to date and redrawn all the line drawings and graphs, frequently with improvement : French mechanical drawing appears to be less detailed than German, and is often clearer. The reproduction of photographs, however, is not as good, some being darker, some lighter, than their German counterparts ; a loss of clarity occurs in most cases. Another and trivial fault is that micrographs are sometimes inverted. The index of this volume seems considerably fuller than that in the German volume, and an especial attraction is a trilingual (French, German, and English) glossary of powder-metallurgy terms, arranged in three sections : French-German-English, English-French-German, and German-English-French, the first of these having a certain number of explanatory remarks in French.

In all, this is a most excellent presentation of the original work, and in the absence of an English edition, should be of much use to English powder metallurgists.—J. P. S.

MASING, G. "*Lehrbuch der allgemeinen Metallkunde.*" 8vo, pp. xv + 620. Illustrated. Berlin, Göttingen, Heidelberg, 1950 : Springer Verlag. (Price DM 59.60 bound, DM 56.– paper).

This textbook is intended primarily for the student of metallurgy but all metallurgists will find stimulating reading and a fund of information. It is one which can be fully recommended for reading because it will indicate how the impact of metal physics has enabled a rational and consistent explanation to be given of many familiar phenomena.

There must obviously be some arbitrariness of choice of subjects to be included in 'general metallurgy.' Professor Masing has chosen to define his field as starting with the metallic state. This means that he has left out of consideration the recent advances in process metallurgy in which thermodynamics and physical chemistry have played so large a part.

After an introduction which indicates the characteristics of the metallic state and some fundamental facts and definitions, there follows a chapter which deals with the bases on which the book is founded. This chapter is concerned with crystallography, the application and results of X-ray diffraction and certain thermodynamic relationships. This should be read with close attention and fully understood, for its methods and implications are of vital importance in the subsequent ones.

The third chapter is concerned with heterogeneous phase equilibria. The author proceeds from a consideration of single-component systems to binary, ternary, and polycomponent systems, the binary systems being particularly well covered. The more usual microscopic, X-ray, and thermal analysis methods of deriving equilibrium diagrams are also described.

The atomic structure of metals forms the subject of the fourth chapter and deals with the various types of bonding in crystals. This treatment is comparatively simple and makes no attempt to discuss bonding from the wave mechanical point of view, though it is possible to describe the results of wave mechanical treatment in a readily understandable way without having to indulge in complicated mathematics.

A short chapter on diffusion is followed by one on crystal growth in a liquid or gaseous environment. This is a particularly excellent chapter which discusses in great detail the functions and formation of nuclei in the initiation and growth of crystals from a melt, a vapour, or by electrodeposition. Of particular interest to the practising metallurgist are those sections which deal with the solidification of technical metals and the effects of cooling conditions on structure, piping, segregation, porosity, and gas evolution.

The author devotes the seventh chapter to the physical properties of metals, including specific heat, thermal expansion, heat and electrical conductivity, magnetic properties, thermoelectricity, and elasticity. The section dealing with the free electron theory of metals and the interaction of electrons and the atomic lattice is well thought out, though one is inclined to think that the treatment of Brillouin zones is not so readily understood as that given by, for example, Hume-Rothery in his "Atomic Theory for Students of Metallurgy."

The atomic theory of slip and work-hardening is dealt with in the next chapter and serves as an example of the elegant way in which modern concepts may be employed to explain phenomena whose general nature has been known for a long time. The section on dislocations is of particular interest. The questions of fatigue, elastic after effect, and creep receive a short discussion in this chapter.

The ninth chapter deals briefly with internal stresses and it is perhaps a matter for some gratification that the only suggested reading matter on the subject is the Institute of Metals' "Symposium on Internal Stresses in Metals and Alloys." The tenth and eleventh chapters deal with recovery and recrystallization, and with phase changes (transformations), respectively. Here, again, the atomistic and energetic viewpoints and the assumption of nuclei as initiating new phases are fruitful in explaining the observed phenomena. The occurrence of age-hardening is treated also as a phase-change process.

The final chapter is concerned with chemical reactions with non metals, *i.e.*, with the attack of gases and electrolytes on metals. It is pleasing to be able to report that in such a short survey the essential features of the modern theories of high-temperature scaling, and of the electrochemical corrosion processes have been covered.

The book ends with an appendix which deals specifically with some of the properties of alloys of iron, copper, aluminium, magnesium, zinc, and nickel.

The book is clearly printed on excellent paper and the illustrations, particularly the photomicrographs, are first-rate. Although there are a few minor errors, they are not such as to confuse, since they usually occur when referring to diagrams and either the diagram itself or the text corrects the mistake. A few names in the index have received wrong spelling or extra initials.—J. PEARSON

POWER, F. D. "*Pocket Book for Miners and Metallurgists.*" Fifth edition. Small 8vo, pp. x + 545. London, 1950 ; Sir Isaac Pitman and Sons, Ltd. (Price 25*s.*)

This book must be almost unique in that its fifth edition appears, nearly 60 years after the first, entirely rewritten by the original author. It will still be of more interest to miners than to metallurgists as, though the sections on mining cover geology, mineral deposits, mining methods, haulage, explosives, the organization of a mine, surveying, ore dressing, etc., that on metallurgy comprises only general information on the qualitative determination of many, and the quantitative estimation of a few, metals. A considerable amount of miscellaneous information on, for instance, logarithms, lubricants, ropes and chains, and mechanical drawing, is also to be found herein.—J. P. S.

TWYMAN, F. "*Metal Spectroscopy.*" 8vo, pp. ix + 569. Illustrated. London, 1951 : Charles Griffin and Co., Ltd. (Price 50*s.*)

Although many experienced workers in the spectrographic field may feel disposed to challenge some of the statements made in Twyman's "Metal Spectroscopy" it cannot be denied that both for interesting reading, and for instruction and information on the techniques of spectroscopy and related subjects it can be strongly recommended. The detailed treatment of many points will be of value to the newcomer in the field, while even the 'old hand' will undoubtedly learn something by the perusal of this volume.

The chapter headings are unfortunately a very unsatisfactory guide to their contents, although this fault is in a great measure overcome by a fairly comprehensive index. The historical introduction covering the first 40 pages forms a useful background and the following chapter presents simple theory in a palatable form.

Several chapters are devoted to a description of various types of equipment, both spectrographs and their accessories, together with helpful comments on their characteristics and availability. The various source units and their applicability to a variety of analytical problems are discussed in a chapter prepared by Walsh, formerly with the British Non-Ferrous Metals Research Association and now with the Commonwealth Scientific and Industrial Research Organization in Australia, some of whose practical experience in this direction is already widely known. Milbourn of Imperial Chemical Industries, Ltd. (Metals Division) has contributed a chapter on electrodes which deals with the subject so exhaustively that criticism becomes difficult.

This part of the book is concluded by a brief survey of procedure and references to other publications from which further information may be obtained; although it is difficult to suggest an alternative layout, the chapter on electronic methods which comes in this section of the book strikes a note of discord, particularly as it deals with some aspects of spectroscopy which are complete in themselves.

Having dealt with the necessary equipment for the performance of analyses and research investigations, the next few chapters provide information on the development of techniques of spectrochemical analysis over the past 50 years or so, and show how the most recent procedures have been tested and applied in practice. The applications described vary from works routine analysis to micro-determinations requiring an extremely high degree of accuracy and recommendations are made for the determination of impurities or major constituents in a very wide variety of materials. Some of these sections have been written by specialists in their particular fields, but a notable omission is any mention of the spectrographic examination of ferro-alloys and some other steelmaking materials—this is probably because little work has been done in this direction.

The concluding chapters give, respectively, an account of the theory, equipment, and techniques in use for X-ray analysis, and a survey of development trends in the spectroscopic field which contains brief references to the application of direct reading and recording units.

Appendices deal with partition chromatography, polarography, and definitions, and a very extensive bibliography follows.

This is a book which can be read with advantage by everyone who claims or desires acquaintance with any part of the field of metal spectroscopy.—J. O. Lay

NEW PUBLICATIONS

Ahrens, L. H. "*Spectrochemical Analysis.*" Pp. xxiv + 342. Cambridge, Mass.: Addison-Wesley Press, Inc. (Price $10)

American Society for Testing Materials. "*Symposium on Ultrasonic Testing.*" Special Technical Publication No. 101. Philadelphia, 1951: The Society. (Price $2.00)

American Society for Testing Materials. "*Symposium on the Nature, Occurrence and Effects of Sigma Phase.*" Special Technical Publication No. 110. 8vo, pp. v + 181. Illustrated. Philadelphia, 1951: The Society. (Price $2.50)

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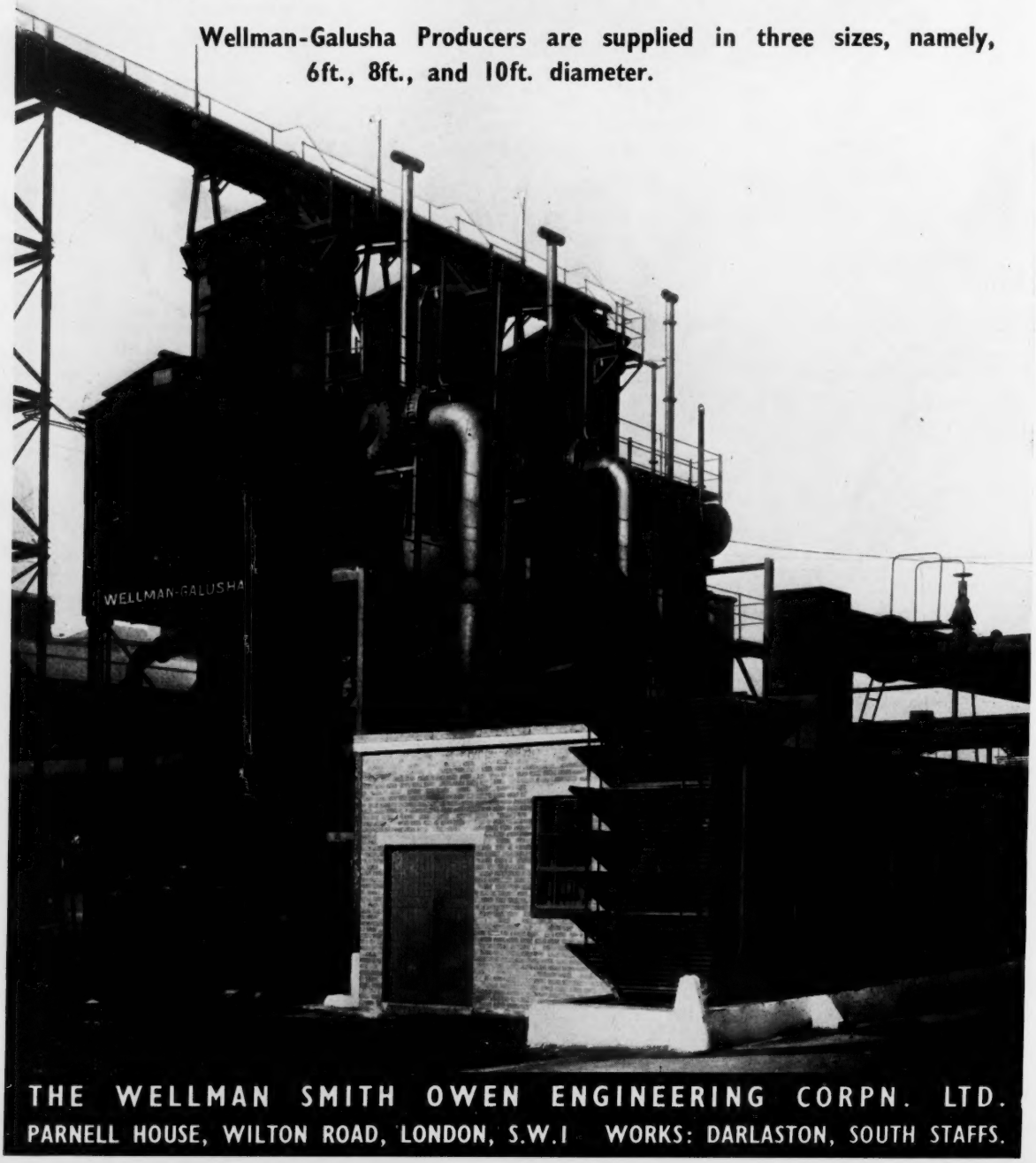

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Microscopical Studies on the Iron–Nickel–Aluminium System

Part II—THE BREAKDOWN OF THE BODY-CENTRED CUBIC LATTICE

By A. J. Bradley, M.A., D.Sc., F.R.S.

SYNOPSIS

Body-centred cubic alloys of the Fe–Ni–Al system may be classified as either β disordered or β' ordered like NiAl. A very narrow two-phase gap may be traced from the melting point downwards, which does not open appreciably above 1000° C. From 950° C. to 750° C. a rapid change takes place. In each isothermal section (950° C., 850° C., 750° C.), the β and β' region constitutes a bay which quickly increases as the temperature is lowered.

Contrary to the experience of earlier investigators, these alloys give rise to microsections which are readily recognized under oil immersion. Three main types of duplex alloy have been identified. In one, an ordered lattice is precipitating from a disordered lattice. At low temperatures islands of order are formed within the mosaic structure and these stack together in small units to form cubes of the ordered lattice. Sometimes the corners of the cubes are rounded, or they may even form perfect spheres instead. In another type of structure disordered matter is being ejected from each mosaic cell, leaving the interior completely ordered. The ejected matter is first deposited at each corner of the mosaic, and then joins together neighbouring corners to form a continuous network. These two types of structure are formed when the disordered or ordered structures are in considerable excess.

When approximately equal amounts of the two phases are present, a lamellar tetragonal structure is formed on 001 planes, analogous to that previously found for FeCuNi, from X-ray evidence. With excess of iron, the ordered NiAl bands break up into cubes or spherules. With less iron, the disordered iron bands are no longer continuous, and in section a maze-like structure is produced.

The approximately pseudo-binary sections, in which these structures are mainly to be found, contain, for the most part, slightly more Al than the vertical plane Fe–Ni–Al. With more Ni, three-phase structures are formed, showing a characteristic combination of the $\beta + \beta'$ with the $\alpha + \beta$ or $\alpha + \beta'$ patterns. The pseudo-binary planes are twisted, so that the exact positions of the phase boundaries require extremely careful delineation.

Introduction

In Part I[1] an account was given of the widening of the miscibility gap between the α face-centred cubic and β body-centred cubic structures in the Fe–Ni–Al system. It was shown that Köster's[2] explanation was fundamentally correct for temperatures immediately below the solidus, and his data for the solidus and liquidus were accepted as a basis for the re-interpretation of these phenomena. Dannöhl's[3] views on the solidus and liquidus were also accepted as substantially correct and extended towards the binary Ni–Al system.

Isothermals were constructed at intervals of 100° C., from 1350° C. down to 950° C. It was found that the miscibility gap gradually widened as Köster had shown, and the exact trend of the boundaries was portrayed in the usual manner, by the disappearing phase method, and the boundaries between the two-phase gap and the single-phase areas, appertaining to the α face-centred cubic and β body-centred cubic structures respectively, were fixed.

The phase boundaries have discontinuities corresponding to the apices of the three-phase triangles, which subdivide the miscibility gap into five separate portions called $\alpha + \beta$, $\alpha + \beta + \beta'$, $\alpha + \beta'$, $\alpha + \alpha' + \beta$,' and $\alpha' + \beta'$ respectively. At lower temperatures the three-phase triangles spread out, especially below 1000° C. In the $\alpha + \beta + \beta'$ area, spreading is suspended at first but develops rapidly at 970° C. The $\alpha + \alpha' + \beta'$ triangle opens out gradually from the melting point.

Corresponding to each three-phase triangle, there is a new miscibility gap in both single-phase areas. Beginning from the melting point, the $\beta + \beta'$ gap remains extremely narrow until the three-phase

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Dr. Bradley is a member of the B.S.A. Group Research Centre, Sheffield.

triangle opens out. From 950° C. to 750° C. the growth of the two-phase region is remarkably rapid. Photomicrographs have been taken, mostly under oil immersion, to illustrate this striking effect. Very characteristic results are obtained, entirely different from those described in the earlier paper for the $\alpha + \beta$, $\alpha + \beta'$, and $\alpha' + \beta'$ alloys. Three-phase alloys also give distinctive photographs. The present paper describes all these very interesting microstructures.

An account of the $\alpha + \alpha'$ and $\alpha + \alpha' + \beta'$ phase-fields will be published separately, although the problems have much in common.

Phase Diagram after Slow Cooling

Bradley and Taylor[4] had already shown that slowly cooled alloys gave a diagram totally different from that proposed by Köster. Köster's data can only be correct at high temperatures, and should not be applied at the lower temperatures, where his times of heat-treatment were really too short for the microscopic method.

The advantage of the X-ray method is that it records the results of instantaneous transformations, so that even with the shortest possible times of cooling, some transformations may be recorded. As the temperature falls, the time of relaxation increases, and ultimately the state of equilibrium may become frozen in. After slow cooling at 10–20° C. per hr., equilibrium is established at about 800° C. The diagram obtained by Bradley and Taylor is therefore, for the most part, intermediate between the 850° and 750° C. isothermals which are reproduced in this paper, but there are certain differences which are discussed elsewhere.[5]

The total time of cooling down to room temperature was two or three days for the X-ray powder photographic technique, whereas the microsections required four days' constant heating at 950° C., 16 days at 850° C., or nine weeks at 750° C. The disadvantage of the powder method is that trustworthy results are difficult to obtain from experiments carried out at higher temperatures, since the state of equilibrium is not conserved by the quenching technique.

The X-ray powder photographs clearly show that the α alloys are face-centred cubic, having a superlattice α' of the Ni_3Al type, while β is body-centred cubic, β' having the NiAl type of superlattice. The interpretation of the two- and three-phase alloys follows in a similar way.

The breakdown of the permanent magnetic alloys near the composition Fe_2NiAl is caused by the splitting of the body-centred cubic structure into two phases.[6, 7] β is disordered and contains little but iron, whilst β' has an ordered structure in which the surplus iron atoms replace nickel and aluminium at random in the NiAl structure.

The present work shows that the compositions of the two phases vary continuously as the temperature is changed, and are very nearly equal at 1050° C., but are widely different at 750° C.

Kiuti's Investigation of the Iron–Nickel–Aluminium System

Kiuti[8] has published an extensive account of the transformations that take place in the Fe–Ni–Al system, proposing an equilibrium diagram which differs considerably from the one given here. Kiuti used a combination of X-ray, microscopic, and dilatometric methods. His main conclusions regarding the $\beta + \beta'$ gap are in agreement with those of Bradley and Taylor, especially in attributing the breakdown of the permanent magnetic structures into two phases to the opening of this gap, but his delineation of the phase boundaries appears to be greatly at fault.

His X-ray powder photographs, although taken with Co-radiation, do not in any instance show the 310 α doublet, from which alone any reliable information about the breakdown of the β structure may be obtained. His photomicrographs really show the breakdown into the $\alpha + \beta$, $\alpha + \beta'$, and $\alpha' + \beta'$ structures illustrated in an earlier paper,[1] and they do not give any recognizable information on the breakdown into the β and β' phases. This is not surprising, since his times of heat-treatment are too short to produce these structures, and the magnification is in no case high enough to observe them properly. With a few exceptions he has not even examined suitable compositions. Not a single recognizable example of a three-phase photograph is shown out of 368 reproductions.

Kiuti failed to distinguish between the $\alpha + \beta$ and $\beta + \beta'$ alloys, but this difficult problem has now been solved, and the results obtained are described in the present paper.

Heterogeneous and Homogenous Precipitation[9]

There are, in general, two types of photomicrograph to be obtained from duplex alloys. In the one, no matter which portion of the alloy is selected, the result is the same.[10] In the other, the nature of the precipitate varies from point to point.[11] Where the precipitate is non-uniform in character a low magnification should be used, but homogeneous precipitation often occurs on quite a small scale, and an oil immersion lens may be necessary. Heterogeneous precipitation is very liable to occur in the grain boundaries, the interior of each grain being free from precipitates.[11] It is therefore essential to examine the grain boundaries and the interior of the grains separately in every case.

With heterogeneous precipitates the new phases are produced separately, both end phases occurring side by side with the original solid solution.[12, 13] In homogeneous precipitation, the original lattice is preserved without recrystallization. Changes in lattice spacing are continuous and there is no breakaway from the original structure, particularly if both end phases have the same crystal structure as the original lattice, with almost identical lattice spacings, *e.g.*, $\beta + \beta'$ alloys.

EXPERIMENTAL

Ternary alloys were prepared from the pure metals in an evacuated high-frequency induction furnace as described in earlier publications, each ingot weighing about 30 g. Lump annealing was carried out, in batches of seven, for about two days at 1250° C. to ensure homogenization. As the photomicrographs show, this heat-treatment is entirely

satisfactory. Each alloy was then sawn into four or more portions, and heat-treated for various times at stated temperatures. The most important results were obtained at 850° C., when the alloys had been heated for 16 days. A batch of alloys was enclosed in a thin nickel basket of cylindrical cross-section and inserted inside an approx. 1-in. dia. porcelain tube at the centre of a horizontal platinum- or Nichrome-wound furnace. The furnace was sealed and evacuated and maintained at a constant temperature for the stated time. Effective temperature control was obtained by a Foster instrument and a constant series of readings was taken on a Cambridge recorder. At the end of the stated time, air was admitted into the tube, and, by means of a hooked rod, the nickel basket was rapidly pulled out of the furnace and plunged into brine to ensure an effective quench.

After polishing and etching, microscopic examination was made on a Vickers projection microscope. The composition of the etchant used, Rosenhain's solution, was 30 g. of ferric chloride, 1·0 g. of cupric chloride, 0·5 g. of stannous chloride, 100 c.c. conc. HCl, made up to 500 c.c. with water. This is double the normal strength, but appears to give better results. When the alloy splits up into two body-centred cubic lattices, etching takes place in a few seconds. The grains of the β or β' phase are very large, and may be up to a centimetre in diameter. The individual crystals show up with bright iridescent colours. Under a low magnification nothing further can be seen unless the α phase is present, but under a magnification of 1000–4000 the structure is found to be duplex, the two phases of the body-centred cubic lattice being extremely closely interwoven. For most of the work an oil-immersion lens was required.

RECOGNITION OF HOMOGENEOUS TWO-PHASE ALLOYS WITH SIMILAR LATTICES, $\alpha + \alpha'$ AND $\beta + \beta'$

An examination[1] of the $\alpha + \beta$, $\alpha + \beta'$, and $\alpha' + \beta'$ alloys showed them to be heterogeneous, the two phases having different structures. When the atoms are thrown out of solution, they have to rebuild a new lattice quite separate from the original one, and the grain boundaries are wholly discontinuous. There must, for this reason, be considerable energy in the boundary zones in which the atoms are changing alignment.

The formation of the two-phase alloys $\alpha + \alpha'$ and $\beta + \beta'$ is entirely different. In this case we are dealing with something more like a change of order. There is, for this reason, no need for a grain boundary to separate them.[14] Each phase may be continuously joined to the neighbouring phase in the microsection with a gradual, not sudden, change in composition. Whenever this is observed it is evidence that the two phases possess the same fundamental lattice, whether purely face-centred or purely body-centred.

Differences of lattice spacing, however, may lead to a sharper declivity in composition at certain points, thereby simulating the behaviour of heterogeneous alloys. For this reason we must be prepared for very great differences in the appearance of the microstructures, according to circumstances. Where the lattice spacings are equal, or nearly so, the transformation merges into an order–disorder change ; when the spacings are entirely different, it becomes indistinguishable from a normal condition of heterogeneous equilibrium. All intermediate stages are possible.

The precipitation of α' from α, or β' from β, is an ordering process. The precipitation of α from α' or β from β' is a disordering process. Either process may, under certain conditions, proceed to completion. On the other hand, both processes may occur simultaneously.

RECOGNITION OF GENUINE THREE-PHASE ALLOYS

The three-phase alloys are easily identified from the structures of the duplex alloys. They share either the characteristics of the $\alpha + \beta$ and $\beta + \beta'$ alloys, or those of the $\alpha + \beta'$ and $\beta + \beta'$ alloys, in the case of $\alpha + \beta + \beta'$. Similar considerations apply to the three-phase $\alpha + \alpha' + \beta'$ alloys, which are to be described separately.

The $\alpha + \beta$, $\alpha + \beta'$, and $\alpha' + \beta'$ patterns are normally much coarser than the $\alpha + \alpha'$ and $\beta + \beta'$ patterns, and this helps in identification, but coarseness is not a safe guide because the sizes of the heterogeneous precipitate vary so much according to circumstances.

$\beta + \beta'$ structures generally form a closely knit pattern, which is invisible under a low magnification, whilst the α phase precipitates in a much coarser form, so that under low magnifications the three-phase structure may be mistaken for $\alpha + \beta$ or $\alpha + \beta'$ only. Magnifications of 1000–4000 have been employed to detect the β–β' separation. The results are perfectly satisfactory for the dual precipitation of α and β from β', but not quite so good for the simultaneous precipitation of α and β' from β. On the other hand, the dual separation of β and β' from α cannot under any circumstances be observed under the microscope, and there is reason to suppose that it never occurs, although its existence is demanded by the phase equilibrium diagram.

Every feature of the $\beta + \beta'$ alloys is duplicated in the adjacent alloys of the three-phase triangle. There is therefore no difficulty in the interpretation of the β–β' boundary of the $\alpha + \beta + \beta'$ phase field. The boundaries on the other two sides are satisfactory near the base, but become less certain near the α apex, which is, moreover, less easy to fix because of the comparatively small irregularity in the boundary of the α-phase field at the point of contact.

This last difficulty does not occur in the $\alpha + \alpha' + \beta'$-phase field, since there is a very sharp break in the β' boundary at the point of contact, but nevertheless there is still no separation of the two like phases as they precipitate from the unlike structure. This behaviour is therefore not a unique characteristic of the $\alpha + \beta + \beta'$-phase field.

MICROSCOPIC DELINEATION OF THE $\beta + \beta'$ BAY

Figures 1, 2, and 3 show isothermal sections of the phase diagram at 950° C., 850° C., and 750° C. respectively. The gradual widening of the gaps between the α or α' and β or β' phases has already

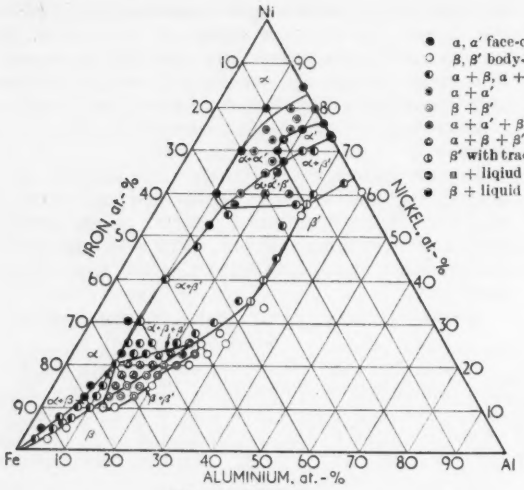

Fig. 1—950° C.

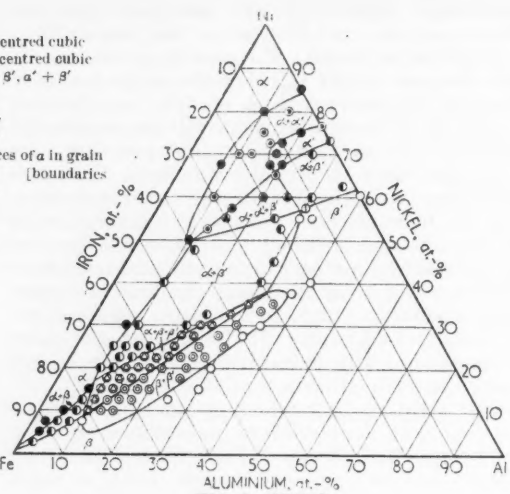

Fig. 2—850° C.

been discussed.[1] It continues from the melting point downwards in most parts of the system, but in the $\alpha + \beta$ region the process is linked with the formation of the austenitic loop; this will be discussed later in connection with the vertical cut through the Fe–NiAl section of the diagram.

With this exception, the sole concern is now the widening of the $\beta + \beta'$ bay, in the β- and β'-phase fields.

The 950° C. Isothermal

In Fig. 1, the $\beta + \beta'$ bay is widening out extremely rapidly near 950° C., as is seen from the vertical cuts perpendicular to the NiAl side, described later, and it is difficult to say whether any given alloy should be inside or outside the two-phase area at this temperature. There are, in fact, four alloys towards the NiAl side which are definitely borderline cases, since they show only the first signs of precipitation. The curve is much flatter here, since the original $\beta + \beta'$ gap is nearer the iron end of the bay.

There are six contiguous three-phase alloys, which help considerably in fixing the actual length of the bay. The other three alloys, which are adjacent to the α apex, must be placed inside the three-phase triangle, although in actual fact the β and β' phases fail to separate from each other when the α phase forms the majority of the alloy, or even slightly less. Further details will be published later.

The 850° C. Isothermal

At this stage, Fig. 2, the $\beta + \beta'$ bay has spread considerably in all directions, but mainly towards NiAl. For the first time, the alloy Fe_2NiAl has become two-phase. The extent of the transformation is extraordinary. Along the line Fe–NiAl, where there were formerly five $\beta + \beta'$ alloys, one of which was a borderline case, there are now ten duplex alloys, in addition to one three-phase alloy. The limiting composition in the direction of NiAl is Fe 26%, Ni 37%, Al 37%. On the one side $Fe_2Ni_3Al_3$ remains single-phase; on the other, $Fe_6Ni_7Al_7$ is already clearly two-phase. A detailed account of

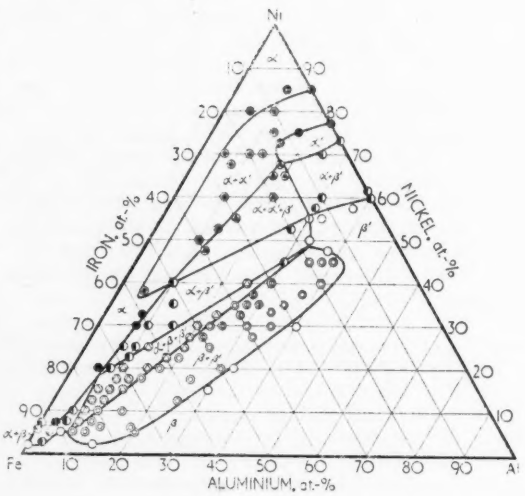

Fig. 3—750° C.

Figs. 1 to 3—Isothermal sections of the phase diagrams for the Fe–Ni–Al system at various temperatures

the photomicrograph of this alloy leads to some very important conclusions regarding the mode of precipitation of β from β'.

In the direction of the iron corner, the greatest extent of the $\beta + \beta'$ phase is not along the line Fe–NiAl, but corresponds to a considerable excess of Al in place of nickel, the actual composition being Fe 83%, Ni 6%, Al 11%. In agreement with this conclusion, the maximum extent of the three-phase triangle is found to deviate considerably from the line Fe–NiAl, being on the Al side at the iron corner but well on the nickel side at the NiAl corner. The actual compositions of the two corners of the three-phase triangle are Fe 81%, Ni 9%, Al 10% and Fe 30%, Ni 38%, Al 32%. Joining these two points, a pseudo-binary line is obtained, which

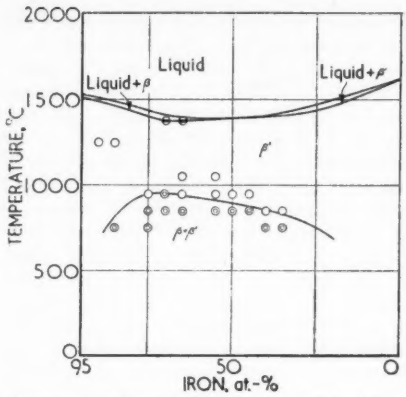

Fig. 4—Section Fe–Ni–Al (+2·5% Al, −2·5% Ni)

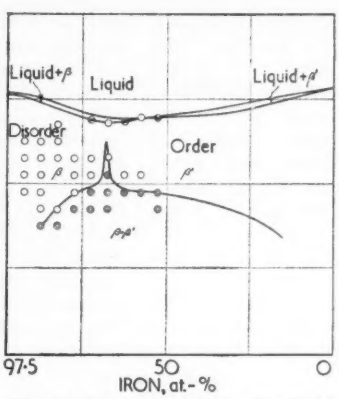

Fig. 5—Section parallel to Fe–NiAl, with excess Al (+1·25% Al, −1·25% Ni)

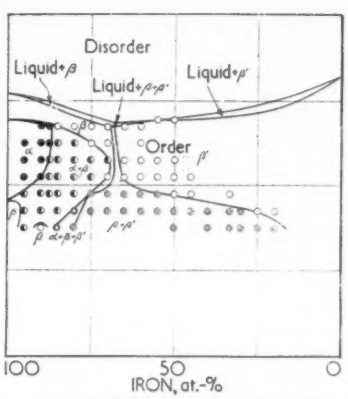

Fig. 6—Section from the iron corner to the composition NiAl

deviates considerably to the NiAl side of the perpendicular.

On the aluminium side, the maximum extent of the bay appears to be along a line containing about 5% more Al and less Ni than the line Fe–NiAl. More information would be desirable, but unfortunately the research had to be concluded before the necessary alloys were made. A particularly important point that has not yet been investigated is the extent of the $\beta + \beta'$ bay in the direction of Fe_3Al.

In the three-phase triangle, 17 genuine triplex alloys have been found, but an additional three alloys near the α corner must be placed inside the triangle, although the β and β' phases cannot be identified with certainty.

The 750° C. Isothermal

This isothermal, Fig. 3, continues to show the same changes that occur between 950° C. and 850° C. The $\beta + \beta'$ miscibility gap widens out in every direction, and the three-phase triangle $\alpha + \beta + \beta'$ is further displaced towards the Fe–Ni side of the diagram. There is an enormous lengthening of the $\beta + \beta'$ edge of the triangle, the β corner moving to Fe 88%, Ni 5%, Al 7%, while the β' corner moves to Fe 18%, Ni 49%, Al 33%.

In the direction of the Fe corner, the bay extends to Fe 89%, Ni 4%, Al 7%, which is extremely close to the β end of the three-phase triangle. In the opposite direction, the limiting composition is Fe 13%, Ni 45%, Al 42%. The most widely spaced duplex alloys are $Fe_{35}Ni_2Al_3$ and $Fe_3Ni_9Al_8$. These values are almost equally removed from the iron corner of the diagram and from the Ni–Al side of the diagram respectively.

On the aluminium side, a whole series of alloys has entered the $\beta + \beta'$ bay for the first time, being single-phase (β or β') at higher temperatures. On the opposite side, they enter the $\beta + \beta'$ bay from the $\alpha + \beta + \beta'$ triangle, which is now displaced to receive alloys that were in the $\alpha + \beta'$ gap at higher temperatures. In a future paper, various series of photographs will be shown to illustrate the passage of alloys through the three-phase triangle as the alloy cools.

It is again to be noted that there are no three-phase alloys near the α corner of the three-phase triangle.

Other difficulties are experienced near the β–β' border of the $\alpha + \beta + \beta'$ triangle. Many alloys that are allotted to the two-phase $\beta + \beta'$ region still contain considerable amounts of the α phase in the grain boundaries, although not in the crystal interiors. This phenomenon will be discussed more fully in connection with the reactions of the β and β' phases, which are so important from the point of view of the permanent magnet alloys.

The remainder of the system, especially the $\alpha + \alpha'$ alloys and the $\alpha + \alpha' + \beta'$ triangle, will be illustrated by a special series of photomicrographs to show the nature of the order–disorder change which takes place in this part of the system.

VERTICAL CUTS PERPENDICULAR TO NiAl

The simple interpretation formerly given by Köster has lead to a satisfactory classification of the two-phase alloys containing one face-centred and one body-centred cubic structure; this was described in Part I. An entirely different type of duplex alloy, in which both phases are body-centred cubic, is considered here; β' is ordered; β is disordered. The whole series of alloys may be considered to be derived from a hypothetical pseudo-binary system of the phenol–water type, in which Fe and NiAl are the respective components. Such a diagram is shown in Fig. 4.

This is one of a series of vertical cuts made along the line Fe–NiAl and parallel to this direction at intervals of $1\frac{1}{4}$% in composition; the simplest picture was obtained by the addition of more aluminium and less nickel. With $2\frac{1}{2}$% of aluminium added to replace nickel, the diagram becomes quite simple again, representing only the decomposition of the β and β' phases. At the β or Fe end, globules of β' are deposited on cooling; at the β' or NiAl end, β is precipitated, but each component contains some of the other in solid solution.

With $1\frac{1}{4}$% of added aluminium, a funnel is observed to extend upwards from the miscibility gap. This

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represents the parting of the ordered and disordered structures. Along the actual line Fe–NiAl, the funnel is found to extend in the shape of a narrow chimney, up to the melting point, where the three-phase region liq. + β + β' is found. More work is needed here at high temperatures. Nearer the iron end of the diagram, a two-phase gap of the $\alpha + \beta$ type is found, separating clearly marked α and β zones. Where the $\alpha + \beta$ and $\beta + \beta'$ zones overlap, $\alpha + \beta + \beta'$ is found.

With $1\frac{1}{4}\%$ of added nickel, the $\beta + \beta'$ area diminishes and is replaced by the $\alpha + \beta + \beta'$ region, which spreads from the iron end. This diagram explains the difference between the $\alpha + \beta$- and $\alpha + \beta'$-phase fields, showing how they are separated by the three-phase fields $\alpha + \beta + \beta'$, just as the β and β' fields in the previous section were separated by the $\beta + \beta'$ chimney.

With $2\frac{1}{2}\%$ of added nickel, the $\alpha + \beta + \beta'$ gap is found to reach the melting point near the invariant plane $\alpha + \beta + \beta'$ + liq. With $3\frac{3}{4}\%$ of added nickel, the $\beta + \beta'$ field almost disappears, and a point of contact of the $\alpha + \beta + \beta'$ area with the α phase is probably reached.

The general course of the solidus and liquidus curves is almost self-evident, and can easily be traced with the help of Köster's data, although he did not determine the two separately. As usual, the temperatures used by the author were somewhat higher than Köster's. A redetermination of the solidus and liquidus is probably desirable.

The Section Fe–NiAl (+ 2·5% Al, − 2·5% Ni)

This section starts at 5% Al in the iron–aluminium system and stretches to 52·5% Al, 47·5% Ni in the nickel–aluminium system (*see* Fig. 4). Above 1000° C. it appears to consist exclusively of a single-phase region containing only β alloys at the iron end (disordered), and β' alloys at the nickel–aluminium end (ordered). From 950° C. downwards the alloys begin to decompose into two phases, rejecting β to the left and β' to the right. As we have seen, the system is essentially of the simple phenol–water type, and is readily understood if interpreted from this angle.

A further simplification can be made, since the tie lines are roughly in the plane of the paper, so that there is little trouble in obtaining a literal interpretation of the results. The system may be divided into two portions: (*a*) to the left of the maximum point of the curve, which we will call β, and (*b*) to the right of this point, which we will designate as β'. It is clear that any β alloy will, on cooling, throw out of solution some of the β' phase, whereas β' alloys will throw β out of solution if they lie on the extreme right of the diagram, but if they are near the centre of the diagram β and β' will part simultaneously.

There are therefore three general ways in which these alloys may break up

$\beta \longrightarrow \beta + \beta'$, β' is precipitated
$\beta' \longrightarrow \beta' + \beta$, β is precipitated
$\beta' \longrightarrow \beta' + \beta$, the phases part

At first sight the first two reactions may be expected to be the exact reverse, *i.e.*, if β' comes out of β solution in the form of spheroids, β might be expected to form from β' in a similar way, but this is not so.

There is an essential difference between the precipitation of β' from β and that of β from β'. Three reasons might be adduced for this fact: (i) the lattice spacing of β' is greater than that of the β phase in contact with it; (ii) the slope of the β boundary is steeper than that of the β' boundary; (iii) the β phase is disordered and the β' phase is ordered. The first reason cannot be cited with any great force because the difference in spacing is not constant from one tie-line to another (see horizontal sections), although the microscopic structures are. We can only conclude that this factor is without influence on the type of precipitate.* The second point is unlikely to be vital because the heat-treatments were carried out at constant temperatures, so that the slope of the phase boundaries is unlikely to be of any importance. There remains the third explanation.

It is clear that the precipitation of a disordered phase from an ordered phase is vitally different from the converse process, while the simultaneous precipitation of an ordered and disordered phase by the splitting of the lattice may be regarded as a third process, distinct from the other two.

The evidence for the solidus and liquidus curves is scanty, but such as there is indicates a minimum to correspond roughly with the maximum point of the $\beta + \beta'$ curve at 70% of Fe. The special significance of this fact can best be found from the adjacent sections.

The Section Fe–NiAl (+ 1·25 Al, − 1·25% Ni)

This is another section parallel to the line Fe–NiAl with extra aluminium in place of nickel (*see* Fig. 5). It stretches from a point at 2·5% of aluminium in the iron–aluminium diagram to a point on the nickel–aluminium diagram with 51·25% of aluminium and 48·75% of nickel. It is very like the previous section but with one anomalous feature. At about 67·5% Fe, 15% Ni, 17·5% Al the decomposition temperature suddenly increases to well over 1050° C., although it remains below 1150° C. This alloy must be considered to be on the borderline between the β and β' phases, although its mode of decomposition places it rather on the β' side.

Apart from this one alloy, which behaves in an anomalous manner, there is no striking difference from the preceding section, and the microstructures of neighbouring alloys belonging to the two sections are very alike in character. This is not surprising as they differ only by 1·25% in atomic composition. For this reason the section has not been investigated in any detail, and it is included in this series mainly to show how remarkable is the sudden change which takes place between this section and the next.

The Section from Fe Corner to NiAl

This section, Fig. 6, from the iron corner to the composition NiAl is noteworthy for the first appear-

* Provided that only slight changes in spacing occur.

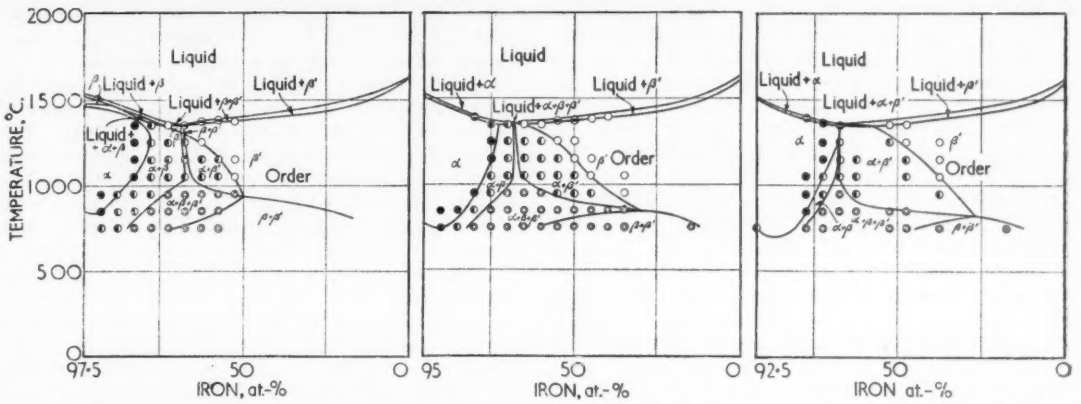

Fig. 7—Section parallel to Fe–NiAl, with excess Ni (+ 1·25% Ni, — 1·25 % Al)

Fig. 8—Section parallel to Fe–NiAl, with excess Ni (+ 2·5% Ni, — 2·5% Al)

Fig. 9—Section parallel to Fe–NiAl, with excess Ni (+ 3·75% Ni, — 3·75% Al)

ance of the austenitic α phase. In spite of the slight change in composition, which amounts to no more than 0·6% by weight near the iron corner, the difference in the appearance of the diagram is remarkable. This would scarcely have been thought possible if the research had not actually been carried out, and it shows the very great importance of such investigations in the region of the iron corner of ternary equilibrium diagrams for the thorough understanding of the different behaviour of all the various alloy systems of which iron is the main constituent.

To establish continuity with the sections previously described, attention is confined to the β′-phase field. In agreement with the previous sections, there are two types of precipitation in this part of the diagram, the precipitation of β from β′ and the simultaneous deposition of β and β′ from solid solution. We cannot trace the precipitation of β′ from β in this section for the following reason.

The β-phase field is no longer predominant, being mainly superseded by α + β alloys. This is the principal change that has taken place. In actual fact this section is very near and almost parallel to the β boundary. The α + β alloys lie on tie-lines which are almost perpendicular to the plane of the paper, passing downwards to a higher nickel and lower aluminium content. This largely accounts for the peculiar nature of the phase boundaries, which at the same time have been drawn to give a faithful representation of the experimental results and to be strictly in accordance with phase-rule principles.

The β boundary makes contact with the α-phase field at 1390° C., whilst at 1350° C. there is a narrow gap, widening rapidly as the temperature falls and the α phase is precipitated. It appears that maximum precipitation occurs at about 1100–1150° C. This is less remarkable than we should suppose, for the α phase itself rapidly becomes less stable *below* this temperature. Thus the *increasing* solubility of iron in the β phase below 1100° C. is not to be ascribed to any special change in the properties of this phase, but rather to the *decreasing* stability of the α phase with which it is in equilibrium. The recovery in the β phase continues as the temperature is lowered and the precipitation of α is steadily superseded.

The α-phase field is quite extensive in character, although in the previous section it was non-existent. This is because of the inherent properties of iron, which are obviously little affected by the addition of quite appreciable quantities of nickel and aluminium in the proportion of the compound NiAl.

The precipitation of β′ from β follows on the same lines as in previous sections, although complicated by the prior precipitation of α; but as β′ precipitates out, α passes back into solution. Whether we cross from the β + α to the β + β′-phase field *via* the single-phase or three-phase region, there will be a complete change in the direction of the tie-lines. In the β + α region they are almost perpendicular, and in the β + β′ region almost parallel, to the plane of the paper. Thus at the higher temperature β precipitates α, richer in nickel but poorer in aluminium, while at the lower temperature it precipitates β′, richer in both nickel and aluminium, but poorer in iron. Simultaneously the β phase itself, which forms the matrix, becomes richer in aluminium but poorer in iron at high temperatures, whilst at low temperatures it sheds both nickel and aluminium, becoming richer in iron.

There is no space in the present paper to illustrate the course of all these reactions, but a special account will be given, in a succeeding paper, of all the changes that may occur in the β- and β′-phase fields as the mode of precipitation changes.

A gap between the β- and β′-phase fields is drawn to extend through to the melting point. It may be objected that there is no experimental justification for this, but the two adjacent sections supply the necessary data. The solidus and liquidus lines are drawn to produce a minimum at their point of intersection with the β + β′ gap, in approximate agreement with Köster's data. Further investigation is required at this point.

The Section Fe–NiAl (+ 1·25% Ni, — 1·25% Al)

This section (*see* Fig. 7), which starts at 2·5% nickel in the iron–nickel system and stretches to

48·75% Al, 51·25% Ni in the nickel–aluminium system, is quite unlike those with excess aluminium, but is not dissimilar from the neighbouring sections on either side. As the nickel content increases and the aluminium content decreases, the face-centred cubic phase becomes steadily more prominent, at the expense of the disordered body-centred cubic structure. The main change from the previous section is, however, the occurrence of an entirely new duplex-phase field $\alpha + \beta'$, in which the α phase is found in conjunction with the ordered β' phase. This area is one in which β' alloys precipitate α on cooling. As a necessary corollary, there is a vast area where the three-phase structures $\alpha + \beta + \beta'$ replace the two-phase $\beta + \beta'$ structures found in the earlier sections. For the first time the following series of reactions is found to occur on cooling :

$$\beta' \longrightarrow \beta' + \alpha \longrightarrow \beta' + \alpha + \beta \longrightarrow \beta + \beta'$$

This series of reactions is not shown to occur on the previous section, but this statement requires modification in the light of more knowledge, (*see* Figs. 8 and 9). A more detailed account must be reserved for a later paper.

The four curves shown separately at the top left-hand side of the previous diagram now come very close together, owing to the decay of the β phase, and the boundaries are rather difficult to trace out, but it is clear that the melting point falls to a minimum at the invariant point

$$\text{liq.} + \beta \longrightarrow \alpha + \beta'$$

This reaction takes place at about 1350° C., the exact composition lying intermediate between this section and that immediately following, possibly about Fe 68·5%, Ni 17·5%, Al 14%.

The Section Fe–NiAl (+ 2·5% Ni, – 2·5% Al)

This section (*see* Fig. 8) is so similar to the foregoing that it scarcely requires any detailed comment. The amount of α phase is greatly increased and the last traces of β are apparent. $\alpha + \beta$ narrows down, but $\alpha + \beta'$ increases. $\alpha + \beta + \beta'$ grows at the expense of $\beta + \beta'$, which is limited to temperatures below 850° C.

The Section Fe–NiAl (+ 3·75% Ni, – 3·75% Al)

The further changes which occur are almost self-evident (*see* Fig. 9). The most important part of the diagram now embraces only the $\alpha + \beta'$-phase field. The funnel-shaped area of the $\alpha + \beta + \beta'$ alloys found in the previous section is now confined to a much narrower wedge between $\alpha + \beta$ and $\alpha + \beta'$, which makes contact with the α phase instead of with the melt.

TYPES OF HOMOGENEOUS DUPLEX ALLOYS, $\beta + \beta'$

Irrespective of differences in lattice spacings, the $\beta + \beta'$ alloys group themselves into three classes. The β phase precipitates the β' phase in globules or cubes. Conversely, the β' phase precipitates the β phase in specks or small particles. These then link together to form a skeleton structure, which may ultimately enclose the original β' structure. Finally, when neither β nor β' is in excess, the phases may deposit simultaneously in a banded structure.

The changes in the β–β' structures may be traced almost the whole way from the Fe corner of the diagram to the neighbourhood of NiAl. The globules of β' deposited from β are in every case intermediate between spheres and cubes, and in the most general case may be regarded as cubes with rounded edges and corners. At first they are well separated from each other, but as the proportion of β' increases, they become strung together along the 100 directions.

The intermediate or lamellar structure consists of parallel slabs etching alternately black or white. β is black, being richer in iron, β' is white, containing more NiAl. These slabs take some time to build up, the original structures being wavy and irregular.

At the β' end, all stages between specks of β precipitate and the complete lamellar banded structure exist. The specks may grow into small independent particles where there is very little β present, or more frequently they throw out threads which link the specks together into a continuous three-dimensional net. Finally the meshes of the network close up to form a box-like structure. This in turn gives place to the parallel planes described above. Such are the changes that occur on adding Fe to the NiAl lattice, until the β and β' phases are present in equal proportions.

Such homogeneous structures have nothing in common with the heterogeneous $\alpha + \beta$, $\alpha + \beta'$, or $\alpha' + \beta'$ structures, described in the earlier publication.[1] In one case the lattice type is preserved, but there is a rearrangement in the atomic distribution ; in the other an entirely new type of lattice is built up.

DESCRIPTION OF THE PHOTOMICROGRAPHS

Formation of Islands Within the Mosaic Structure

It is instructive to make a quantitative survey of the $\beta + \beta'$ structures. This is especially useful at 750° C. and 850° C. At higher temperatures, where diffusion is more rapid, agglomeration takes place and the results cannot be related so well to the original lattice. At the lower temperatures it is found that the original crystal mosaic is in some degree retained if only very small quantities of precipitate are formed.

The structure may or may not have been ordered before decomposition sets in. Whichever process occurs (*i.e.*, β' precipitating from β or β precipitating from β') the results are at first the same. The Ni and Al atoms *immigrate* to the centres of the mosaics ; Fe atoms *emigrate* to the corners of the mosaics. Direct experimental evidence for the reaction is forthcoming from the decomposition of the β' phase, especially at the composition $Fe_6Ni_7Al_7$. However, for the moment, only Fe-rich alloys will be considered.

If only a little nickel and aluminium are present, the ordered structure first builds up 'islands' such as have previously been described, especially for the Cu–Ni–Al system.[15, 16] These are small regions of order, each completely immersed in a disordered lattice—islands of the Ni_3Al phase (α') are being deposited from the Cu-rich complex.

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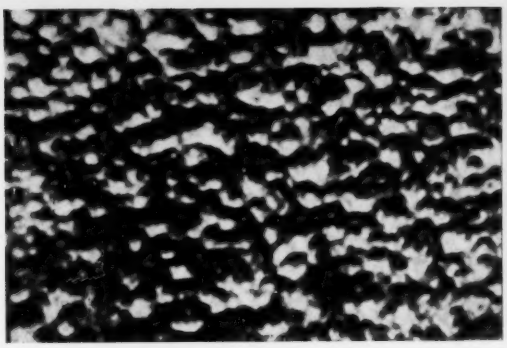

Fig. 10—Ni 7·5%, Al 10%, 750° C. $\beta + \beta'$ × 4000

Fig. 11—Ni 6·25%, Al 12·5%, 750° C. $\beta + \beta'$ × 4000

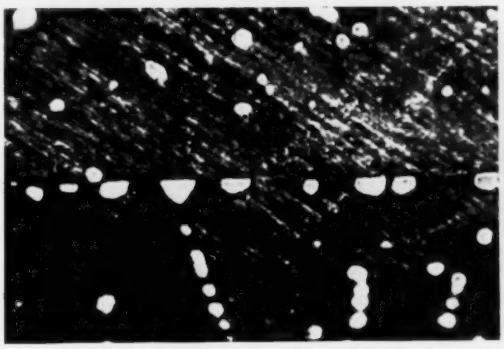

Fig. 12—Ni 10·0%, Al 12·5%, 850° C. $\beta + \beta'$ × 2000

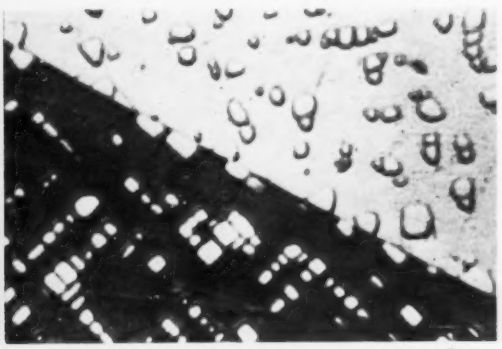

Fig. 13—Ni 10·0%, Al 15·0%, 850° C. $\beta + \beta'$ × 3000

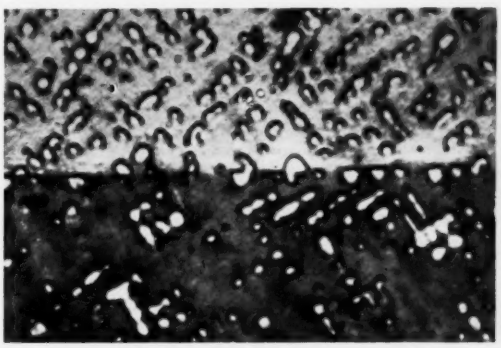

Fig. 14—Ni 12·5%, Al 15·0%, 850° C. $\beta + \beta'$ × 1750

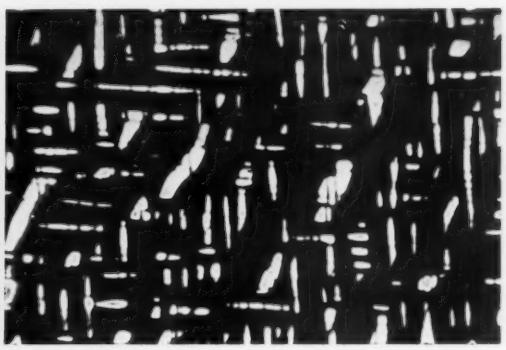

Fig. 15—Ni 12·5%, Al 15·0%, 950° C. $\beta + \beta'$ × 2000

Fig. 16—Ni 12·5%, Al 17·5%, 850° C. $\beta + \beta'$ × 1000

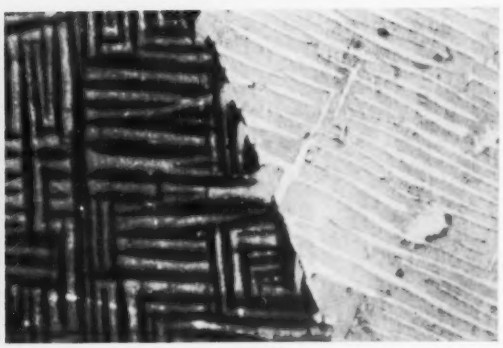

Fig. 17—Ni 12·5%, Al 17·5%, 950° C. $\beta + \beta'$ × 2000

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[*To face p.* 240

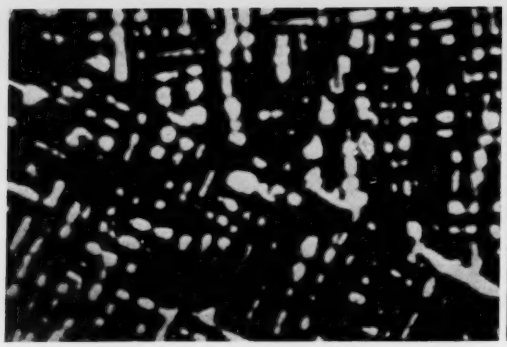

Fig. 18—Ni 15·0%, Al 17·5%, 850° C. $\beta + \beta'$ × 1500

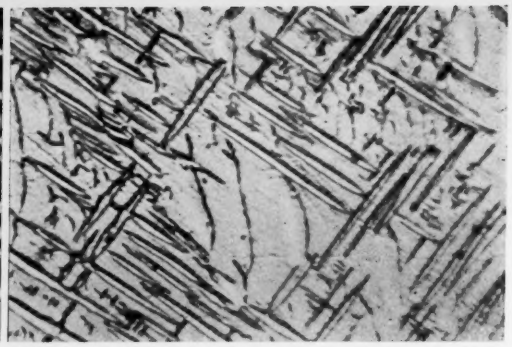

Fig. 19—Ni 15·0%, Al 17·5%, 950° C. $\beta + \beta'$ × 2000

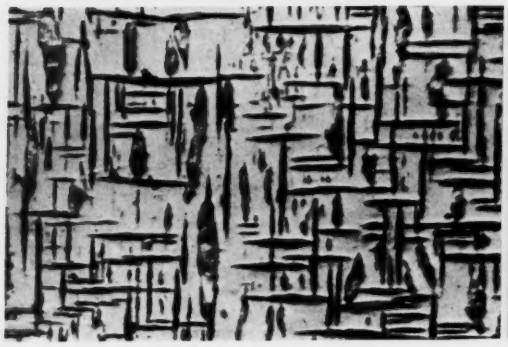

Fig. 20—Ni 15·0%, Al 17·5%, 1,050° C. $\beta + \beta'$ × 2500

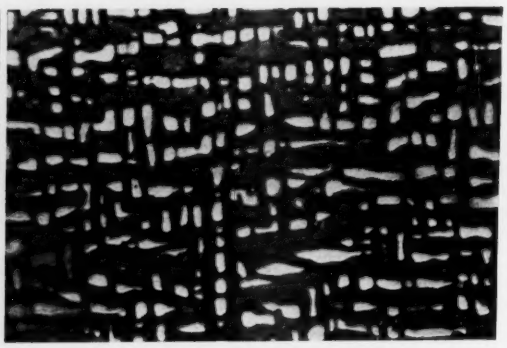

Fig. 21—Ni 15·0%, Al 20·0%, 850° C. $\beta + \beta'$ × 2500

Fig. 22—Ni 20·0%, Al 20·0%, 850° C. $\beta + \beta'$ × 4000

Fig. 23—Ni 20·0%, Al 20·0%, 950° C. $\beta + \beta'$ × 4000

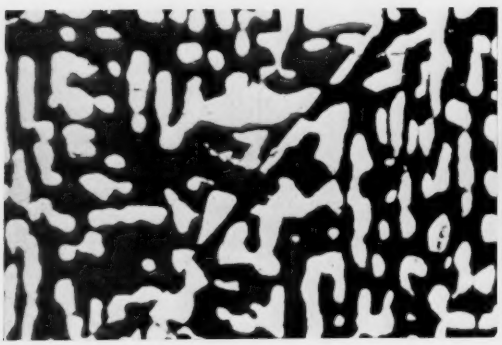

Fig. 24—Ni 17·5%, Al 17·5%, 950° C. $\beta + \beta'$ × 2000

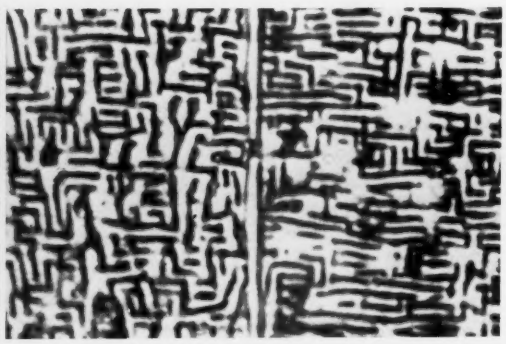

Fig. 25—Ni 20·0%, Al 25·0%, 850° C. $\beta + \beta'$ × 1750

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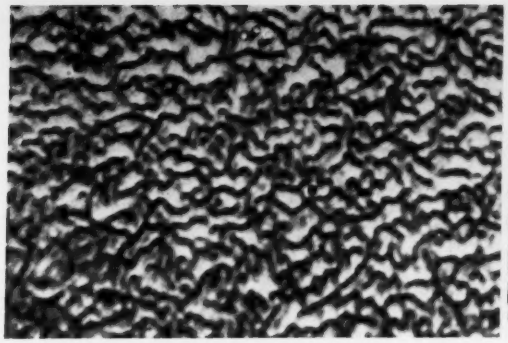

Fig. 26—Ni 17·5%, Al 25·0%, 750° C. $\beta + \beta'$ × 4000

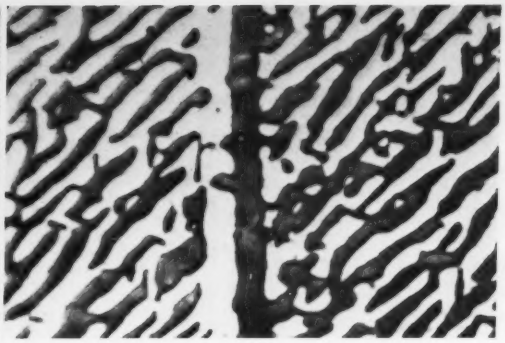

Fig. 27—Ni 17·5%, Al 25·0%, 850° C. $\beta + \beta'$ × 2500

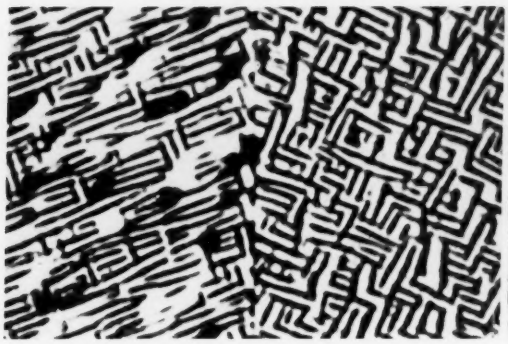

Fig. 28—Ni 22·5%, Al 25·0%, 850° C. $\beta + \beta'$ × 1500

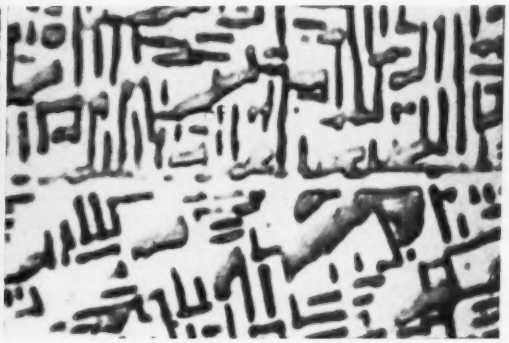

Fig. 29—Ni 22·5%, Al 27·5%, 850° C. $\beta + \beta'$ × 3000

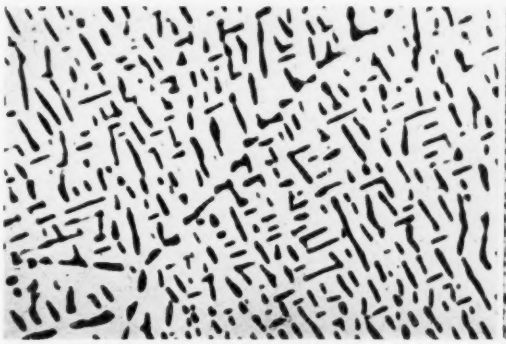

Fig. 30—Ni 30·0%, Al 30·0%, 850° C. $\beta + \beta'$ × 2000

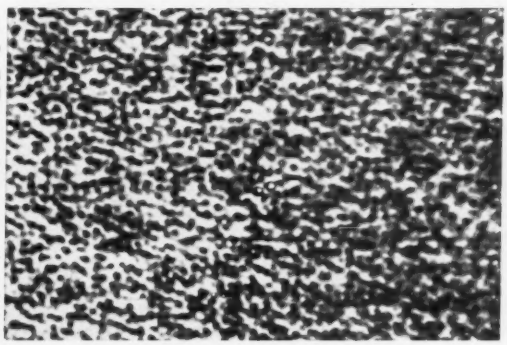

Fig. 31—Ni 30·0%, Al 35·0%, 750° C. $\beta + \beta'$ × 4000

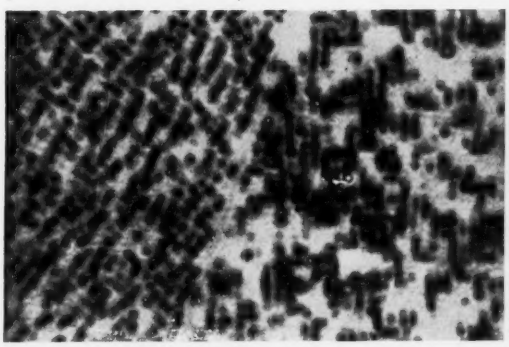

Fig. 32—Ni 35·0%, Al 35·0%, 850° C. $\beta + \beta'$ × 4000

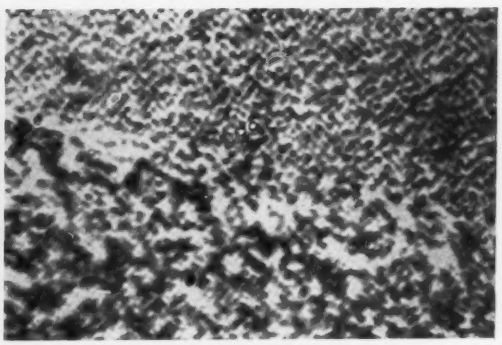

Fig. 33—Ni 35·0%, Al 35·0%, 750° C. $\beta + \beta'$ × 4000

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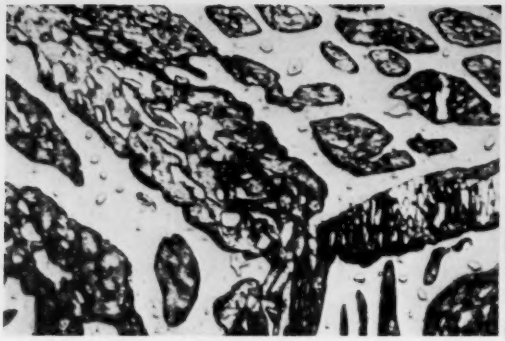

Fig. 34—Ni 22·5%, Al 17·5%, 950° C.
$\alpha + \beta + \beta'$ × 750

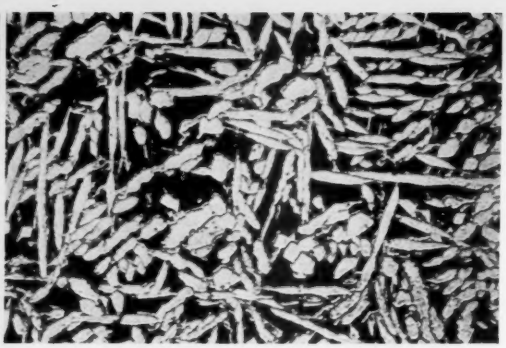

Fig. 35—Ni 22·5%, Al 17·5%, 850° C.
$\alpha + \beta + \beta'$ × 1000

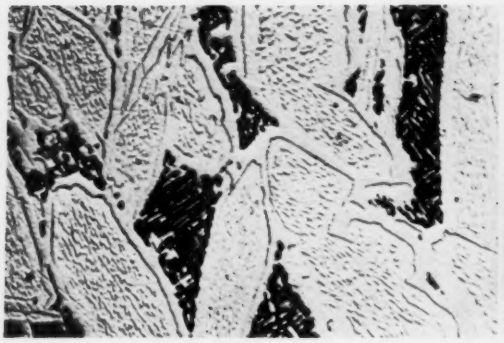

Fig. 36—Ni 22·5%, Al 17·5%, 850° C.
$\alpha + \beta + \beta'$ × 750

Fig. 37—Ni 22·5%, Al 17·5%, 750° C.
$\alpha + \beta + \beta'$ × 3000

Fig. 38—Ni 27·5%, Al 20·0%, 850° C.
$\alpha + \beta + \beta'$ × 2000

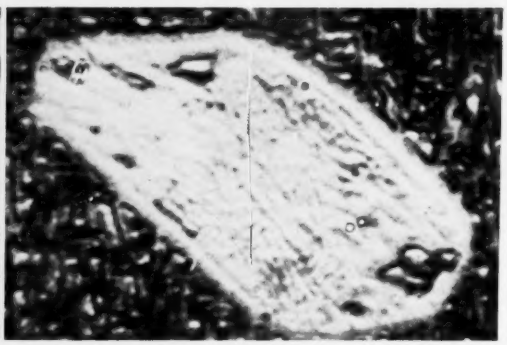

Fig. 39—Ni 27·5%, Al 20·0%, 750° C.
$\alpha + \beta + \beta'$ × 4000

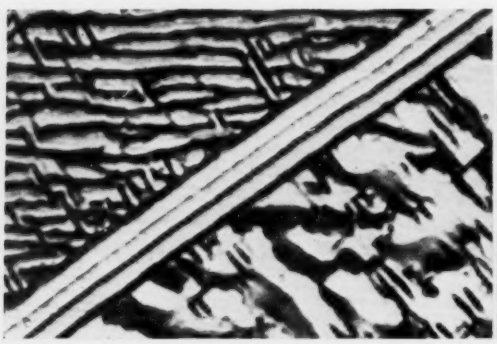

Fig. 40—Ni 22·5%, Al 22·5%, 850° C.
$\alpha + \beta + \beta'$ × 1500

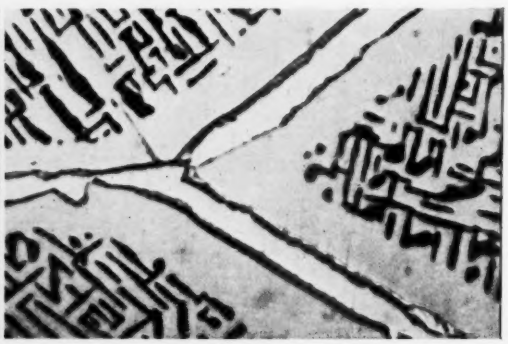

Fig. 41—Ni 27·5%, Al 27·5% 850° C.
$\alpha + \beta + \beta'$ × 2000

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In the present instance, there is X-ray evidence to indicate that there are similar islands of the NiAl phase (β') being deposited from the β lattice during slow cooling, especially at the composition $Fe_{18}NiAl$.[4] The microscopic evidence shows that this alloy is single-phase at 750° C. In neighbouring alloys, which the microscope shows to be two-phase at 750° C., the regions of order are at first extremely small and are very much tinier than the size of a single mosaic cell. This is the precipitation stage. The first stage of precipitation, on the visual scale, consists of the formation and agglomeration of the 'islands' within each mosaic cell. These concentrate in little spherules, each smaller than a single cell.

Simultaneously, the cell walls are thickened by the deposit of the surplus iron atoms, while they steadily become denuded of nickel and aluminium. The first two photographs show the microscopic representation of this stage in the decomposition of the β phase by the precipitation of the ordered β' phase.

Fig. 10—Fe 82·5%, Ni 7·5%, Al 10%, 750° C. $\beta + \beta'$. This alloy remains in a single-phase state down to 850° C. and only decomposes reluctantly below this temperature. The microscope reveals a most peculiar mosaic structure. A pattern of this type has not been found in a single-phase β alloy, although the structure is probably for the most part the original mosaic present before decomposition set in. The structure is very fine and really requires the use of the electron microscope in order to give a higher resolving power.

Fig. 11—Fe 81·25%, Ni 6·25%, Al 12·5%, 750° C. $\beta + \beta'$. The result is not dissimilar to that shown in Fig 10. Under a low magnification the alloy shows only very large (several mm.) polyhedral grains, darkened to a different extent in each case. After enlargement the darkened grains are found to exhibit a mosaic structure. The probable explanation is that the interior of each mosaic is beginning to form an ordered structure, gathering groups of NiAl molecules together into knots or clusters, and at the same time pushing the surplus Fe atoms into the walls of the mosaic. There is therefore no connection between the ordered material in different mosaics. The amount of ordered material formed may be judged from the phase equilibrium diagram, and hence the wall thickness of the mosaic may be estimated. About 10% of the material appears to be ordered. In linear dimensions this means that one third of the cross-section of a cell would be ordered, the remainder totally disordered. It is, however, impossible to decide whether the whole of this ordered material is grouped together near the centre of the mosaic; probably it is not.

Globular and Cubic Structures in the Formation of Ordered Lattices

As already mentioned, where the disordered phase (β) is in excess of the ordered phase (β'), the ordered phase deposits in isolated regions. At low temperatures these form islands of 50–100 Å. in size conforming in all respects to the parent lattice. They probably do not break away unless the alloy is heated. At a suitable temperature (750–850° C.) they burst through the walls of the mosaic cell, to build up globules about 1μ (10^{-4} cm.) in size, with definite grain boundaries. These are formed like raindrops, by the internal forces of cohesion between the nickel and aluminium atoms. The iron atoms constitute the matrix within which the reaction occurs.

It is well known that the attraction between nickel and aluminium is so great that there is a considerable reduction in the atomic volume when NiAl is formed from the elements. The globules thus appear to be formed by a process of shrinkage. The process is the reverse of that described by Mott and Nabarro,[17, 18] which postulates expansion on precipitation. Consequently the conditions for maximum stability are reversed. Instead of plates or needles being the more stable form, globules will give the required condition for minimum free energy, the effect being not unlike that of gravity in the case of the earth.

The building up of cubes introduces a complication. The cube faces are flat, and not curved, because the forces of attraction are not directed to the centres of the particles, but are at right angles to the cube faces as in the formation of crystals of fluorspar. The rounding off of cube edges and corners, which sometimes occurs, does not correspond to the formation of secondary facets; in fact every stage between cubes and spheres occurs, but the globular structures are the more common. The globules have definite sizes and orientations. If there is a too great proportion of NiAl present, they form linked structures and ultimately plates parallel to 100 planes. These structures are now described in detail.

Fig. 12—Fe 77·5%, Ni 10%, Al 12·5%, 850° C. $\beta + \beta'$. The photograph shows two grains with different orientations. The dark background is the residue of the disordered structure rich in Fe. The white blobs present in both grains are the precipitated β' phase, which is the ordered structure rich in NiAl. They do not cross from one grain into another, and do not disturb the position of the grain boundary. This proves that there is no breakdown in the original lattice. All that has happened is that the atoms are rearranging themselves by a new kind of order–disorder transformation. The blobs have the appearance of distorted spheres which have grown until, in many cases, neighbouring blobs have run into each other.

Fig. 13—Fe 75%, Ni 10%, Al 15%, 850° C. $\beta + \beta'$. Two very large grains are visible. There is great contrast in etching, and again there is the perfectly straight grain boundary, which, however, has no definite orientation in regard to the crystal planes. The precipitating particles of the ordered phase have a very clear-cut boundary separating them from the ferrite matrix. There is no question of the two structures merging into each other. These particles under no circumstances cross the boundaries of the original grains, which proves that they adhere rigorously to the original lattice.

The ordered granules form perfectly rectangular blocks. In some cases these build up almost perfect cubes. As the blocks grow they do not run into each other, but preserve perfectly distinct boundaries, which indicates that the lattice planes may have got out of step, because of differences between the dimensions of the matrix and the precipitating phase. There is little or no rounding of the corners of these blocks. This is especially remarkable in view of the very high degree of magnification.

It is clear that ordered blocks are aligned along the cube faces of the original crystal. Their size varies from $2 \cdot 5 \times 10^{-5}$ cm. up to 10^{-4} cm. As later evidence will show, the lower limit corresponds exactly to the size of a mosaic cell. The blocks are therefore formed either from single mosaic cells or by stacking together a number of neighbouring mosaic cells. For example, 64 neighbouring mosaic cells would form a single cubic block of dimensions equal to one micron. However, the blocks are not necessarily cubic; thus the dimensions might be $3 \times 4 \times 5$

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mosaic units, so that they could contain altogether 60 cells. One feature is, however, perfectly clear; under no circumstances are there any re-entrant angles. The photograph shows that there is a greater chance of development for neighbouring cells than for cells which are not in contact with each other.

One of the two grains is exactly orientated to show a cubic face; this etches black, although the ordered blocks remain white. The other grain has a totally different orientation, so that the cubic blocks appear to be truncated. The etching reagent does not darken this face.

Comparison of the Breakdown at 950° C. and 850° C.

The next series of photographs compares the extent of precipitation at 950° C. and at 850° C., and in one case an example is given at 1050° C. The vertical cuts already described show that the series at 950° C. is distinctly nearer the β' boundary than the series at 850° C. if like compositions are compared. The transition from the series at 850° C. to the series at 950° C. is therefore equivalent to a movement towards the NiAl end of the system at constant temperature.

The structures at 950° C. are also on a considerably bigger scale than the structures at 850° C.

Banded Structures

The banded structures found in the $\beta + \beta'$ region of the Fe–Ni–Al diagram consist of alternate plates of the disordered and ordered material lying parallel to the 100 planes. The thickness varies according to the temperature of heat-treatment, but successive black bands are generally about 1μ apart and the black and white bands are usually almost equal in width. This appears to be the sole condition for the occurrence of these structures.

If one constituent is in excess, then the characteristics of that end of the duplex bay appear. If β is in excess, the white plates break up into β' globules. If β' is in excess, the black plates are no longer continuous; a mazelike structure is produced, in which the black Fe-rich areas are disconnected and form isolated patches completely surrounded by the ordered NiAl structure. Some specimens are banded at 950° C., but globular at 850° C. This is caused by the rapid change in solubility between the two temperatures, as shown in the vertical cuts.

Fig. 14—Fe 72·5%, Ni 12·5%, Al 15%, 850° C. $\beta + \beta'$. The ordered phase is present in blobs, about 1μ in size, which are intermediate in shape between spheres and cubes. Growth takes place by the amalgamation of neighbouring blobs, in directions at right angles, tracing out 100 planes. Two grains are shown with different orientations. Although the blobs do not cross the original grain boundaries, where adjacent blobs lie on opposite sides, they appear to merge, which suggests a change in orientation.

Fig. 15—Fe 72·5%, Ni 12·5%, Al 15%, 950° C. $\beta + \beta'$. The contrast between the two phases is very great, and no detailed comment is necessary.

Fig. 16—Fe 70%, Ni 12·5%, Al 17·5%, 850° C. $\beta + \beta'$. The same characteristics are apparent with the tendency of the blobs to mark out 100 planes even more pronounced.

Fig. 17—Fe 70%, Ni 12·5%, Al 17·5%, 950° C. $\beta + \beta'$. There is a marked contrast between this and the previous photograph, because the specimen lies much nearer to the β' boundary at 950° C. The structure consists of alternate bands of ferrite and NiAl compound, the original grain boundary being perfectly preserved. There is no deposit in the grain boundaries, showing that the reaction consists only of an order–disorder change within the original lattice. The distance between adjacent bands is 1·5 μ. A most remarkable feature is the variation in the etching characteristics of the ferritic phase, which is white in one grain, but black in the other. The NiAl phase is always grey.

Fig. 18—Fe 67·5%, Ni 15%, Al 17·5%, 850° C. $\beta + \beta'$. A characteristic example of the globular type. Increasing amounts of the β' phase cause greater agglomeration of the blobs, which are about 2μ in size.

Fig. 19—Fe 67·5%, Ni 15%, Al 17·5%, 950° C. $\beta + \beta'$. The majority of the alloy is seen to be in the β' form, the β phase being precipitated in plates parallel to the 100 planes. Thus the position is reversed as compared with that at 850° C. The ferrite, however, does not blacken, although the section is taken almost parallel to the 001 plane, the 100 and 010 planes being almost vertical.

Fig. 20—Fe 67·5%, Ni 15%, Al 17·5%, 1050° C. $\beta + \beta'$. This photograph is a solitary example of a $\beta + \beta'$ alloy formed at 1050° C. The structure is similar to that at 950° C. and the β phase again shows signs of blackening against the pale β' background.

Fig. 21—Fe 65%, Ni 15%, Al 20%, 850° C. $\beta + \beta'$. This is another photograph from the β side of the two-phase region. The ordered structure forms rectangular blocks but re-entrant corners are noticeable in this case.

Fig. 22—Fe 60%, Ni 20%, Al 20%, 850° C. $\beta + \beta'$. The main interest of this structure lies in its contrast with the following one. The bulk of the alloy consists of the disordered β phase, which has clearly separated from the ordered β' phase in the background. This structure is quite unique in appearance and indicates a complete separation of the two phases.

Fig. 23—Fe 60%, Ni 20%, Al 20%, 950° C. $\beta + \beta'$. The precipitation of ferrite is much sparser than it is at 850° C. (*see* Fig. 22). The striped pattern corresponds to alternate plates of ordered and disordered material. There are no longer definite boundaries between the two phases, because the lattice spacings are now more nearly equal.

Fig. 24—Fe 65%, Ni 17·5%, Al 17·5%, 950° C. $\beta + \beta'$. This contrasts with the previous photograph in showing a much greater proportion of the β phase. The original grain boundary is clearly preserved and, although the blobs of the β' phase have run together to a very considerable extent, they do not cross the grain boundaries, showing that the original crystal orientation is preserved.

Lamellar Structures at 750° C. and 850° C.

Fig. 25—Fe 55%, Ni 20%, Al 25%, 850° C. $\beta + \beta'$. Two crystal grains are shown. The Fe content is not enough to form a continuous black precipitate, so that the structure already forms a maze-like pattern. A remarkable feature is the wavy nature of the bands.

Fig. 26—Fe 57·5%, Ni 17·5%, Al 25%, 750° C. $\beta + \beta'$. This shows that ferrite is being rejected from the NiAl matrix. There is a difference in scale at the two temperatures, which corresponds to different stages in the decomposition of the alloy.

Fig. 27—Fe 57·5%, Ni 17·5%, Al 25%, 850° C. With the higher temperature the two constituents build up into standing waves, like sand ripples. The wavelength is 2μ. The waves do not cross the original grain boundaries where a transverse barrier is found.

Here, precipitation at 750° C. does not yield any mosaic pattern. The irregular structure is clearly independent of the original mosaic, and follows only from a local breakdown; the Fe is forced out of the original lattice and deposited in ridges. Later, a more regular structure is built up, which clearly results from the dynamics of the breakdown, and not from the original pattern of the structure. Although the basic lattice is maintained unimpaired, the mosaic is certainly destroyed.

Fig. 28—Fe 52·5%, Ni 22·5%, Al 25%, 850° C. $\beta + \beta'$. This alloy decomposes at about 950° C. At 850° C. the proportions of the two phases are about equal. It is a beautiful example of the lamellar structure, and a fuller account of the remarkable magnetic properties, which appear to be peculiarly associated with this type of structure, will be given in a future paper. There are two crystals, one being almost parallel to a 100 plane, since the black blobs correspond to lamellæ approximately in the plane of the paper. The crystal boundary is most clearly defined by a sharp change in orientation.

Fig. 29—Fe 50%, Ni 22·5%, Al 27·5%, 850° C. $\beta + \beta'$. The alloy was originally composed of large grains, several mm. in size, which were single-phase above 900° C. The white line across the centre of the photograph separates two such grains. As usual, the black precipitate is the Fe-rich phase, which is being formed as lamellæ parallel to the 100, 010, and 001 planes. Under these circumstances the directions of the lines of precipitation will depend upon the orientations of the crystals in a very simple manner. If, to make the simplest assumption, the section is parallel to a cube face then only two directions of precipitation will be found, and these will be exactly at right angles to one another. Moreover, the thickness of the lamellæ should be the same in the two directions. Secondly, suppose the section is parallel to a 110 face, then the lamellæ will again be composed of two sets of lines at right angles, but they will be thicker in one direction than in the other, and will, moreover, be elongated so as to differentiate the $1\bar{1}0$ direction from the 001 direction. A third possibility is that the section should be parallel to 111. In this simple case the traces of the lamellæ will obviously be equilateral triangles.

Any random section will be intermediate between these three positions. Between a 100 and a 110 plane, a section will show a purely rectangular pattern, but if it is tilted slightly towards a 111 direction, the trace of the third plane will at once be introduced.

The lamellæ vary between 1000 Å. and 3000 Å. in thickness, and are up to 60,000 Å. in length.

Fig. 30—Fe 40%, Ni 30%, Al 30%, 850° C. $\beta' + \beta$. This consists of lamellæ each approximately 1000 Å. × 2000 Å. × 2000 Å. in dimension. The black plates are the rejected ferrite, while the white background corresponds to the original NiAl type of structure.

Fig. 31—Fe 35%, Ni 30%, Al 35%, 750° C. $\beta' + \beta$. The structure consists of minute specks of ferrite being deposited at the corners of the mosaic blocks, with tentacles thrown out to link them to neighbouring specks.

Relation of the Mosaic to the Formation of Homogeneous Precipitates

At 750–850° C., the precipitation of small amounts of the disordered lattice (Fe) from the ordered lattice (NiAl) leads to the deposition, first of specks at the corners of the mosaics, which are found to be cubes in perfect alignment, $2{\cdot}5 \times 10^{-5}$ cm., and then to the formation of a complete three-dimensional network of this size. The network is gradually blocked in, giving hollow cubes, with ordered materials (rich in NiAl) in the interior, and disordered material (iron-rich) in the walls of the cubes. With more iron, the specks agglomerate at once, and the mosaic structure breaks down, leading to the types of structure that have been described.

Fig. 32—Fe 30%, Ni 35%, Al 35%, 850° C. $\beta' + \beta$. This photograph is extremely important because it shows the first definite evidence for the precipitation of ferrite at the corners of the mosaics. The average size of a mosaic is 3×10^{-5} cm. From the phase diagram the volume of the precipitate in proportion to the matrix is 1:14. In linear proportions this corresponds to a ratio of 5:12. The average linear dimension of a single spot if every cube corner were occupied is $5/12 \times 3 \times 10^{-5}$ or $1{\cdot}25 \times 10^{-5}$ cm., which corresponds to ½ mm. with a magnification of 4000.

The chance of cutting through a decomposed portion of a cube is equal to the ratio of the depth of a single spot to the whole cube edge *i.e.*, 5:12. The number of mosaics per sq. cm. $= (5/6)^2 \times 100 = 70$. Therefore the chance of cutting through a decomposed portion is $(5/12) \times 70 = 29$. This means that we should expect to observe 29 nuclei/sq. cm. The actual number observed is about 28, which is in extremely good agreement. The distribution of spots of course varies statistically in different parts of the specimen. The following list gives the actual observations for 13 different sq. cm. : 29, 27, 23, 21, 23, 31, 43, 33, 28, 22, 33, 27.

From the above the actual size of the nucleus corresponds to a cube 1250 Å. in length. The number of atoms per c.c. can be calculated from the interatomic distance 2·5 Å., and this gives a nucleus containing 100,000,000 atoms after 16 days' heat-treatment at 850° C.

Fig. 33—Fe 30%, Ni 35%, Al 35%, 750° C. $\beta' + \beta$. The proportion of precipitated material has increased from 1/14 to 1/5, as may be seen from the phase diagram. The size of each mosaic has decreased slightly to $2{\cdot}5 \times 10^{-5}$ cm. Nuclei will be present at the corners of the mosaic cells as before. Suppose that the nuclei are approx. 1000 Å. in size, then the proportion of material in each nucleus will be $\left(\frac{1}{2{\cdot}5}\right)^3 = \frac{1}{15}$. Thus 1/15 only of the matrix would be precipitated at cube corners. But we know from the phase diagram that there is actually 1/5 to be accounted for. This leaves 2/15 of the volume of the mosaic cell, which corresponds to precipitation either along cube edges or on cube faces. In either case this provides for the fainter linkages that are observed both in this photograph and in every other case where the proportion of precipitate exceeds about 1/15.

Assuming precipitation in the cube faces, it may be calculated that the precipitate would be distributed in a layer about 50 atoms thick. However, this cannot be the case since it would mean that the material is distributed uniformly between each nucleus : this is untrue since some points are joined by very much thicker lines than others.

The correct explanation is that precipitation occurs not in cube faces but along cube edges. Thus wherever a section parallel to a cube face intersects the original nuclei, it will also intersect the matter in the cube edges, so that each nucleus will be joined to neighbouring nuclei. Where the section in the plane of the paper misses the nucleus, only a faint spot will be observed corresponding to the point of intersection of a vertical cube edge. Such fainter spots will not be joined to neighbouring spots, but thick spots will be joined together.

The amount of precipitate in cube edges, assuming that they receive all the precipitate uniformly, may be calculated. The length of each cube edge equals $(1{\cdot}5) \times 10^{-5}$ cm., exclusive of the nuclei at the corners, and there are 12 edges, each shared between four neighbouring cubes, *i.e.*, 3 edges per cube. Thus the amount precipitated in each edge equals 2/45 × the total volume, or $2/3 \times 10^{-15}$ c.c. The cross-section of each edge is therefore equal to $\frac{2}{3} \times \frac{1}{1{\cdot}5} \times 10^{-10} = 0{\cdot}45 \times 10^{-10}$ sq. cm. The thickness is therefore 700 Å. or 300 atoms. On the observed scale this would correspond to 0·3 mm., *i.e.*, rather less than the thickness of the corner spots, 0·4 mm. It is, of course, difficult to make any direct measurements on this small scale, but the magnitude of the effects is approximately correct.

Three-Phase Alloys

A series of four photographs is reproduced to show successive stages in the decomposition of a three-

phase alloy. This alloy crystallizes from the melt as $\beta' +$ liquid (β' primary). On cooling, α is precipitated, beginning at 1300° C. At about 950° C., the alloy enters the three-phase field.

Fig. 34—Fe 60%, Ni 22·5%, Al 17·5%, 950° C. $\alpha (+ \beta) + \beta$. This photograph is therefore a borderline case. The white background is the original β' phase. The grey precipitate is the α phase, but it is considerably broken up by internal decomposition, and the β' phase is reprecipitated from the α phase on cooling.

Fig. 35—Fe 60%, Ni 22·5%, Al 17·5%, 850° C. $\alpha + \beta + \beta'$. The appearance is quite altered. Instead of a grey precipitate on a white ground there is a white precipitate on a black ground. The precipitate is still α, but it etches white by comparison with β, which now appears to constitute the majority of the matrix, instead of β'.

Fig. 36—Fe 60%, Ni 22·5%, Al 17·5%, 850° C. $\alpha + \beta + \beta'$. The enlarged photograph reveals the true nature of the alloy. Not only is α precipitated from β', but internal decomposition of the two phases occurs simultaneously. Inside the α phase, β' is being rejected. Outside the α grains, β (black) and β' (white) are intermingled, while at the same time β is completely isolated from α by a surrounding zone of β'.

Fig. 37—Fe 60%, Ni 22·5%, Al 17·5%. $\alpha + \beta + \beta'$. The $\beta + \beta'$ complex has grown at the expense of the $\alpha + \beta'$ complex. The alloy is passing out of the three-phase triangle into the $\beta + \beta'$ region.

Fig. 38—Fe 52·5%, Ni 27·5%, Al 20%, 850° C. $\alpha + \beta + \beta'$. This is a characteristic three-phase alloy, consisting mostly of $\beta' + \alpha$, in accordance with its position in the phase diagram. The white background constitutes the β' phase, a single phase between 1300° C. and 1350° C. The α phase alone precipitates down to about 860° C., then the black β phase is first thrown out of solution.

Fig. 39—Fe 52·5%, Ni 27·5%, Al 20%, 750° C. $\alpha + \beta + \beta'$. This alloy has traversed the three-phase region, and the α phase has almost vanished. The alloy is now mainly $\beta + \beta'$, although there are a few large chunks of α left. The photograph is specially selected to show one. A smaller magnification, although more suitable for showing the relative proportions of α and β, did not reveal the $\beta + \beta'$ complex, containing the two phases in almost equal amounts, with a very wavy structure.

There is here no question of following the lines of a definite mosaic structure. Precipitation takes place by heaping up the iron atoms in ridges (black) alternating with troughs from which the nickel–aluminium lattice has rejected all surplus iron atoms. This photograph represents a comparatively early stage in decomposition, although the alloy has already received nine weeks' heating at 750° C. The periodicity (3000 Å.) corresponds with the mosaic dimensions, but the amount of decomposition is too great to preserve the mosaic structure.

Fig. 40—Fe 55%, Ni 22·5%, Al 22·5%, 850° C. $\beta + \beta'$ with α in grain boundaries. This alloy, according to the phase diagram, should at no time precipitate the α phase. In fact, both at 950° C. and at 850° C. thick slabs of the α phase are deposited in the original grain boundaries. Although these slabs are about 5000 atoms thick, they represent only about 1 part in 2000 of the whole material, since the interior of each grain contains no α phase after 16 days' heat-treatment.

The grain boundary consists of seven successive bands. In the centre is a white band (α), 1·6 μ thick, surrounded on either side by thin black lines (amorphous layer) separating it from two lateral white bands (β'), each slightly wider than the central band. On the outer sides are two more black bands (β) each about 0·6 μ thick. These thicknesses should all be slightly reduced to allow for a possible inclination to the vertical.

The interiors of the two crystals look extremely different, but this is because of their entirely different orientations. The one shows two directions making a small angle with each other, while the third has an entirely different inclination. This crystal is twisted slightly from a 110 plane, towards a 111 plane. The crystal planes appear to be 1·8 μ apart, but an allowance must be made for inclination, giving, say, 1·3 μ.

The other crystal shows a remarkable type of pattern. It is evidently orientated with a 001 plane exactly in the plane of the paper, so that, instead of cutting at right angles to them, we are cutting thin slices through them. On the other hand, the 100 and 010 planes intersect the plane of the paper exactly at right angles, and consequently the distances are the actual vertical distances between adjacent 100 planes. The actual values are about 1·1 μ.

Fig. 41—Fe 45%, Ni 27·5%, Al 27·5%, 850° C. $\beta + \beta'$ with α in grain boundaries. The occurrence of α precipitation in the original grain boundaries contrasts forcibly with the very different β precipitation in the interior of the crystals. The complete absence of the α precipitate inside the crystals is in accordance with the phase diagram, but the occurrence of the α phase in the grain boundaries is not. A discussion of this phenomenon will be deferred to a later paper.

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XUM

The Function of Energizers in Pack Carburizing

By A. Hultgren

SYNOPSIS

A number of small-scale pack-carburizing tests on a low-carbon steel, mainly at a carburization temperature of 925° C., are described. Various ways in which the energizers K_2CO_3, Na_2CO_3, and $BaCO_3$ may be placed in the box with crushed charcoal and with the objects to be carburized are investigated, and also the effect on carburization of different methods of sealing the box. It is shown that K_2CO_3 or Na_2CO_3 may be effectively applied as a layer on top of the charcoal, whereas $BaCO_3$ may be applied as a thin coating on the surface of the objects to be carburized, preferably with a binding agent such as lacquer.

The effects of the different energizers are compared, and the conditions required for good carburization when a carburizer is used repeatedly are determined; it is found that a minimum amount of fresh charcoal, equal to about 10% of the charge, must be added to and mixed with the spent carburizer each time it is re-used, a small amount of energizer being added occasionally to compensate for the slight loss that may occur by evaporation and in handling.

Experiments are described in which, to determine the reactions that take place in a carburizing box, a 1 : 1 N_2–CO_2 mixture is allowed to pass at a measured rate of flow through a layer of heated charcoal, with and without admixed substances, and the amount of CO_2 remaining in the outgoing gas is measured. The experiments indicate that a rapid reaction in which the energizer takes part, and which has a low CO_2 value at equilibrium, determines the composition of the gas in the box.

Introduction

SPECIALLY added 'energizers' or 'activators' have been used in compounds for pack-carburizing since 1861, when Caron[1] introduced his carburizing mixture consisting of 60% of crushed charcoal and 40% of barium carbonate.

Sutton and Ragatz[2] and Fong and Ragatz[3] have contributed to the understanding of the accelerating action of the energizer on the carburization of steel. The former workers, in a series of carburizing experiments made over a range of temperatures from 700° to 950° C., found a slight superiority in depth of carburization for Na_2CO_3 over $BaCO_3$, when 15% of these substances was added to powdered charcoal, whereas the addition of 15% of $CaCO_3$ produced no improvement in the poor results obtained with unmixed charcoal powder.

Common energizers were tried in combination with several different carbonaceous substances: the best were found to cause a soot deposit on the carburized steel specimens. It was assumed in such cases that carbon was also deposited on the carbonate particles.

On repeated use of the carburizer, and without fresh additions of any kind, the depth of carburization was gradually reduced. This applied to unmixed charcoal as well as to mixtures with Na_2CO_3, $BaCO_3$ or $CaCO_3$: soot deposit on the steel surfaces was found when Na_2CO_3 or Ba_2CO_3 was added, but not in the other two cases. The successive decreases in activity were thought to be caused, for charcoal mixed with $CaCO_3$, by the driving off from the charcoal of volatile substances, and for charcoal mixed with Na_2CO_3 or $BaCO_3$, by a similar reaction, together with the coating of energizer particles with soot.

It is frequently considered that the carbonate would gradually decompose during annealing, the CO_2 produced reacting with carbon to form CO. As a corollary, it is often assumed that a used compound would regain its activity if the metallic oxide were allowed to re-absorb CO_2. The validity of these ideas has been disproved by carefully conducted experiments.[2]

Fong and Ragatz, using unmixed charcoal powder and charcoal mixed with various carbonates and oxides, determined the change in CO_2 content of the mixtures after annealing at a number of temperatures in the range 650–950° C. for differing periods, and air-cooling the box. They were able to prove that, for common carburizing temperatures, most of the CO_2 contained in the carbonate–charcoal mixtures disappeared at the highest temperature. For the Na_2CO_3 mixture, at 900° C., only about 2% of the total CO_2 remained after a few minutes, and no change occurred on continued annealing: for the $BaCO_3$ mixture, at 900° C., the amount of CO_2 which remained became constant at 35% after 1 hr. The hydroxide–charcoal mixtures rapidly absorbed CO_2 at moderate temperatures, and lost most of it at higher temperatures.

It was also established that the accelerating effect on carburization went on as before, after the evolution of CO_2 from the energizer–charcoal mixtures had ceased. Thus it was directly proved that the acceleration was not connected with gradual decomposition of the carbonate, in agreement with the results obtained by Sutton and Ragatz.[2]

The authors concluded that the accelerating action of the energizers results from the maintenance of a high CO content in the box atmosphere, as compared with that in a box containing unmixed charcoal. They assumed that the CO_2 evolved in the carburizing reaction at the steel surface is rapidly disposed of by reaction with Na and Na_2O in the one case and with BaO in the other, these reagents being continuously re-formed by the reaction of carbonate with charcoal. It is not clear whether the CO/CO_2 ratio thus maintained approximates to or exceeds the ratio for equilibrium with charcoal. If the former is true, the energizing action would be equivalent to accelerated re-establishment of the gas–charcoal equilibrium, which is continually being disturbed at the steel surface; if the latter, the carbon activity of the atmosphere would exceed that of the charcoal.

Manuscript received 21st September, 1950. Dr. Hultgren is Professor of Metallography at the Royal Institute of Technology, Stockholm, Sweden.

The present paper describes experiments to discover the effect on carburization when the relative positions of charcoal, energizer, and steel objects in the carburization vessel were varied. Certain details of procedure, particularly the method of sealing the boxes, were standardized.

When reproducible results had been obtained, it was found that different energizers responded differently according to their location in the box. The effect of $BaCO_3$ is limited to its immediate surroundings, whereas K_2CO_3 and Na_2CO_3 exert full energizing effect at great distances from their original positions in the box. This observation led to experiments to confine the $BaCO_3$ addition to a layer on the steel surface, and to simplify the addition of K_2CO_3 or Na_2CO_3 by placing suitable quantities, separated from the charcoal and the steel, generally at the top of the box. After both series of experiments were concluded, attention was directed to the repeated use of the same carburizing mixtures, and the precautions necessary to retain their carburizing efficiency. Finally, in order to throw some light on the function of energizers in pack carburizing, experiments were carried out in which a CO_2–N_2 mixture of known composition was passed at a measured rate through a layer of heated charcoal powder, unmixed, or mixed with different energizing substances, and the CO_2 content of the outgoing gas was determined.

EXPERIMENTAL PROCEDURE

The specimens were machined from a 19-mm. dia. bar with the following composition :

C, 0·17%; Si, 0·29%; Mn, 0·44%; P, 0·011%; S, 0·026%

Unless otherwise stated, half-cylinders were employed, obtained by sawing a turned cylinder 18 mm. in dia. × 10 mm. in length, along a diameter. On each carburized specimen, a section was prepared through the centre, normal to the bar axis, and the depth of carburization was determined at three places at the circular contour, the average being reported. When ranges of depths are given, they refer to two or three specimens treated simultaneously. Two depth values were measured, to the point where hypereutectoid carbide disappears (d_c), and to the point where hypoeutectoid ferrite appears (d_f).

The carburizing boxes were made from pieces of tubing with welded-on bottoms, and were provided with loose flanged lids (*see* Fig. 1*a*).

For charcoal–$BaCO_3$ mixtures, boxes and lids made from heat-resistant steel were suitable. When mixtures containing K_2CO_3 or Na_2CO_3 are used, however, heat-resistant steel rapidly fails, owing to fluxing of the chromium-rich oxide : for such carburizers, carbon-steel boxes and lids served well, when the outside surfaces were provided with an aluminium layer applied by the Moeller dipping process.

New boxes of carbon or heat-resistant steel provide a large additional carbon-consuming surface during carburization, and may therefore cause a reduced carburization depth in the packed parts. In the present investigation, coating of the interior surfaces of new boxes with a $BaCO_3$ binder layer has been tried, with apparent success, to accelerate the saturation of these surfaces.

After preliminary experiments, the following measures were taken to secure a good seal :

(1) On top of the charge, under the lid, was placed a steel plate 10 or 15 mm. thick fitting loosely inside the box and turned to a spherical outside surface, as shown in Fig. 1*a*. In this way, a narrow passage for the inlet and outlet of gas was provided, and the compound was held tightly packed in this annular space. Tilting of the plate did not alter the fit, or cause sticking.

(2) The lid was luted to the box with a refractory cement, Refractite, which becomes finely porous when heated to carburization temperatures, while at the same time it retains a certain strength, and does not crack.

A box-resistance furnace, of inside dimensions 17 × 27 cm., and height 13 cm., was used for the carburizing experiments. Four boxes were usually treated at the same time. The temperature distribution in the furnace was such that the results for the two boxes placed near the door showed slightly less depth of carburization than did those for the boxes placed at the back of the furnace ; the difference was of the order of the overall experimental error. Since the thermocouple was liable to be affected by the reducing atmosphere of the furnace, it was calibrated for every experiment.

The temperature generally used for the carburizing experiments was 925° C., maintained for 20 hr. The boxes were placed in the furnace when it had reached 500° C., and the heating from 500° to 925° C. took 3 hr. At the end of an experiment, the boxes were taken out and allowed to cool in air.

After it had been noticed in the preliminary tests that new boxes gave poor or only fair results, the final experiments were carried out using ' seasoned ' boxes.

The carbonaceous material generally used was crushed charcoal, originating from coniferous and foliaceous Swedish trees. No difference in results could be traced to the different origins of the charcoal.

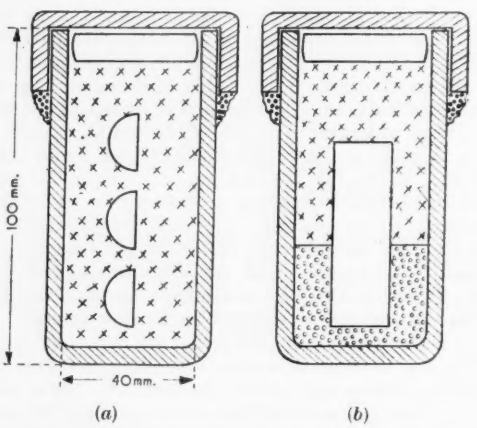

Fig. 1—Carburizing box : (*a*) with top plate, containing standard specimens, (*b*) containing rod-shaped specimen surrounded by carbonate and charcoal

According to Åkerman and Särnström,[4] charcoal from Swedish trees varies in ash content from 0·6 to 1·5%, the main components being CaO, 30–40% ; K_2O + Na_2O, 13–23% ; MgO, 5–10% ; CO_2, 15–25%. Of the alkali oxides, K_2O predominates. The charcoal used was screened to a particle size of 1–3 mm., 1–5 mm., or 1–10 mm., generally to within the first range. It was normally not dried before use, and in a few test series it was washed as described later. The energizers were finely powdered ; chemically pure and commercial grades showed similar energizing properties. When the energizer was mixed with the charcoal, no binder was added.

DETAILED TEST RESULTS

The detailed results of the experiments, conducted under various conditions of carburizing, are presented in sub-sections for clarity. It should be mentioned that under the experimental conditions described, and using a good carburizing compound, the following results were obtained : $d_f = 1·5–1·7$ mm., $d_c = 0·5–0·7$ mm. For charcoal alone, corresponding figures were : $d_f = 1·0–1·3$ mm., $d_c = 0·1–0·3$ mm., probably indicating variation in the energizing ingredients inherently contained in the charcoal.

Charcoal and Energizer Mixtures

A rod 18 mm. in diameter × 55 mm. long was placed along the axis of the box, with its lower end 5 mm. above the bottom. Inside the box was packed a layer of energizer 30 mm. deep, with a layer of charcoal on top (Fig. 1*b*).

The maximum depth of carburization was always obtained at or near the junction between charcoal and energizer. The following depths were determined for different energizers :

Energizer	Top		Maximum		Bottom	
	d_f, mm.	d_c, mm.	d_f, mm.	d_c, mm.	d_f, mm.	d_c, mm.
K_2CO_3	1·3	0·5	1·5	0·7	1·0	0
$BaCO_3$	1·1	0·3	1·5	0·5	0	0
,,	1·3	0·3	1·5	0·5	0	0
,,	1·2	0·2	1·5	0·7	0	0
$SrCO_3$	1·1	0·2	1·5	0·5	0	0
$MgCO_3$	1·4	0·4	1·6	0·6	0	0
$CaCO_3$	1·1	0	1·5	0·5	0	0

The favourable effect shown for $CaCO_3$ does not agree with the results of other experiments in which $CaCO_3$ was added ; K_2CO_3 displayed a considerable 'spreading power,' as was also shown by the fact that it appeared to have been absorbed uniformly by the charcoal. Its melting point is 891° C. Other experiments showed that K_2CO_3 and Na_2CO_3 under suitable conditions, share the property of spreading to great distances in the charcoal.

Although $BaCO_3$ produced a satisfactory energizing effect near the junction, it seemed to add little to the carburizing power of charcoal at the upper end of the rod, and it almost prevented carburizing at the lower end, around which it had sintered in a solid lump, so preventing the admission of gas to the steel surface. The remaining energizers, like $BaCO_3$, lack 'spreading power.'

The absence of spreading power in $BaCO_3$ might also signify that, if it were applied only to or near the steel surface surrounded by charcoal, it would maintain its accelerating effect on carburization, since it would not extend to the whole interior of the box and thus become diluted. Following this tentative conclusion, a series of experiments was made with specimens provided with a coating containing $BaCO_3$. Such specimens were carburized in charcoal.

Coating Containing $BaCO_3$. Unmixed Charcoal

The coating was first applied by dipping the specimens in a mixture of $BaCO_3$ powder and water. On drying, it cracked easily and was brittle. A sludge prepared from Zapon lacquer and $BaCO_3$ powder proved to be satisfactory : it dried quickly after dipping and formed a strong coating.

Numerous experiments were made with different proportions of $BaCO_3$ and lacquer in the coating, making 1–4 dips and drying between successive dips. The coated specimens were packed in unmixed charcoal and subjected to the standard heating cycle. Often fully satisfactory carburization was obtained, but occasionally the results were poor, showing little or no acceleration. The charcoal was then carefully washed before use ; after this treatment, good carburization invariably resulted from the use of a suitably thick $BaCO_3$ lacquer coating on the specimens. Washing was done in the following sequence :

(*a*) In hot 5% hydrochloric acid for 2 hr., and then decanted
(*b*) In hot distilled water for 2 hr., and then decanted
(*c*) In cold distilled water for 40 hr., and then decanted.

In one experiment, three specimens were spaced equally, half-way up the box, which was filled with washed charcoal. For uncoated specimens, the values $d_f = 0·9–1·3$ mm., $d_c = 0–0·1$ mm. were obtained.

For similar specimens twice dipped and dried in a sludge containing 60 g. of $BaCO_3$ in 100 ml. of lacquer and treated in the same way, the values were $d_f = 1·5–1·7$ mm., $d_c = 0·4–0·8$ mm. Similar results were obtained after one dip in a mixture of 140 g. of $BaCO_3$ and 100 ml. of lacquer, which represents about 0·06 g. of $BaCO_3$ per sq. cm. of steel surface. When the coating contained less $BaCO_3$, poorer results were obtained, whereas a coating containing more $BaCO_3$ gave no improvement.

Specimens Partially Coated with $BaCO_3$. Unmixed Charcoal

It was thought that carburization could perhaps be confined to a certain portion of the steel surface, after applying the $BaCO_3$ coating to that portion, and packing in washed charcoal. Experiments were therefore made with three specimens in the box, each specimen being coated over half of its surface. Coatings of various thickness were tried, and results were as follows :

Coating (wt. of $BaCO_3$ mixed with 100 ml. of lacquer), g.	No. of Dips	Carburization	Coated Portion	
			d_c, mm.	d_f, mm.
60	1	Good	1·4–1·6	0·8–1·0
140	1	Poor	0·8–1·3	0·0–0·6
140	2	Poor	0·7–1·0	0·2–0·3
140	3	Good	1·4–1·5	0·7–0·8
			Uncoated Portion	
60	1	Fair	1·2–1·4	0·0–0·8
140	1	Good	1·4–1·6	0·7
140	2	Good	1·4	0·6–0·7
140	3	Good	1·5	0·7

The thickest coating may be assumed to provide sufficient reaction surface with $BaCO_3$ so that both the coated and the uncoated parts of the steel surface receive enough CO for good carburization. The medium coating would produce enough CO to supply the uncoated part only, and under those conditions, the coating would retard the transfer of the CO generated at its outside to the inside. Finally, the thin coating would not form an obstacle to that transfer, and the coated part would be well carburized, whereas there would not be enough $BaCO_3$ reaction surface to satisfy the uncoated part. In this discussion, it has been assumed that the regeneration of CO_2 formed at the steel surface takes place in the region of contact between $BaCO_3$ and charcoal.

It would appear from these experiments that controlled local carburization cannot readily be attained by the use of partial $BaCO_3$ coatings.

Coating of $BaCO_3$ in Washed Charcoal with Additions of K_2CO_3

The favourable effect, brought about by thoroughly washing the charcoal, on the carburization of $BaCO_3$-coated specimens packed in unmixed charcoal indicates that such washing removes some constituent or constituents that interfere with the action of the coating in the carburization process. It was suspected that K_2CO_3 might be such a constituent, and carburization tests were therefore made on $BaCO_3$-coated specimens packed in washed charcoal, with the addition of K_2CO_3 either to the charcoal or to the coating.

In one series, coated specimens (dipped once in a sludge consisting of 140 g. of $BaCO_3$ in 100 ml. of lacquer) were packed in washed charcoal, with a top layer of K_2CO_3, and subjected to the standard heating cycle. Each box contained three standard specimens equally spaced in a vertical row. It will be shown later that adding the K_2CO_3 in this way is equivalent to mixing it with the charcoal. Results were as follows :

Depth of K_2CO_3 Layer, mm.	Equivalent Portion of Mixture, %	d_f, mm.	d_c, mm.
None	...	1·5	0·7
1·5	5	1·0–1·6	0·4–0·8
3	10	1·2–1·3	0·5–0·6
6	20	1·0–1·5	0·4–0·7
9	30	1·1–1·4	0·4–0·7

In another experiment, four coated specimens were placed half-way up in washed charcoal mixed with 18% of K_2CO_3, with the following results :

Coating (wt. of $BaCO_3$ mixed with 100 ml. of lacquer), g.	No. of Dips	d_f, mm.	d_c, mm.
60	1	1·5	0·8
100	1	1·2	0·4
140	1	1·2	0·6
140	2	1·5	0·7

In two further experiments, specimens coated with mixtures of K_2CO_3 (or Na_2CO_3) and $BaCO_3$ in different proportions were packed in a vertical row in washed charcoal. Results were as follows :

Expt. No.	Coating (wt. of substance mixed with 100 ml. of lacquer)	d_f, mm.	d_c, mm.
1	15 g. K_2CO_3 + 75 g. $BaCO_3$	0·4	0
	30 ,, ,, + 60 ,, ,,	0·7	0
	45 ,, ,, + 45 ,, ,,	1·0	0·3
2	5 ,, ,, + 85 ,, ,,	0·2	0
	10 ,, ,, + 80 ,, ,,	0·2	0
	10 ,, Na_2CO_3 + 80 ,, ,,	0·1	0

In all these tests, parallel experiments carried out under standardized carburizing conditions gave satisfactory results. It would seem that the presence of K_2CO_3, in sufficient quantity at any rate, retards carburization of $BaCO_3$-coated steel in washed charcoal. It may well be that the inherent amount of K_2CO_3 in unwashed charcoal is sufficient to produce a noticeable effect of this kind.

Charcoal, with K_2CO_3 or Na_2CO_3 Added as a Separate Layer

The fairly uniform carburization depth obtained in an experiment with a steel rod surrounded partly by charcoal and partly by K_2CO_3 or Na_2CO_3 suggested new experiments to ascertain the spreading power of K_2CO_3 and Na_2CO_3 when applied in a layer on top of the charcoal, beneath the plate. In those experiments, unwashed charcoal, standard specimens (two or three in each box), and standard boxes were used. The time of heating at 925° C. was, as before, 20 hr., and the results were as follows :

Depth of Top Layer of K_2CO_3, mm.	Equivalent Portion of Mixture, %	d_f, mm.	d_c, mm.
5	16	1·3	0·3
10	29	1·4–1·5	0·3–0·4
15	39	1·4–1·5	0·3–0·4

In another series of tests the heating time at 925° C. was varied, with the following results:

Depth of Top Layer of K_2CO_3, mm.	Time of Heating, at 925° C., hr.	d_f, mm.	d_c, mm.
10	15	1·3	0·2–0·4
10	20	1·5	0·4–0·5
10	36	1·9–2·3	0·6

In all cases, the carbonate appeared to have been absorbed by the charcoal. The bottom specimens were as deeply carburized as the top specimens.

Experiments were made next in an industrial furnace using larger square boxes of welded carbon-steel plates. As in earlier tests, a loosely fitting steel plate was placed on top of the charge inside the box, and a lid was finally luted to the box.

In the first experiment the box was 25 cm. square and 16 cm. high. Fifteen standard specimens, uniformly spaced at three levels in a diagonal plane, were packed in unmixed charcoal, the particle size being 1–5 mm. At the top, 10 mm. under the plate, a 12-mm. thick layer of K_2CO_3 (representing about 33% by weight of the mixture) was applied. The box was heated for 18 hr. at 930° C., and then cooled in air. The carburization results were uniform : d_f= 1·5–1·6 mm., d_c = 0·8–0·9 mm.

In another box of the same size, placed beside the first one in the furnace, the same number of specimens were packed, and, in addition, seven steel rods 22 mm. in dia. × 220 mm. long were distributed in a layer above the standard specimens and 10 mm. below the 12-mm. K_2CO_3 layer. All other conditions were the same for the two boxes. The results for the specimens were : d_f = 1·6–1·7 mm., d_c = 0·9–1·0 mm.

The third experiment was similar to the first, but an 8-mm. thick layer of K_2CO_3 was used, representing about 25% of the mixture ; it gave, after the same heating cycle, d_f = 1·5–1·6 mm., d_c = 0·8–0·9 mm.

A larger box, 25 × 25 cm., height 30 cm., was used for the fourth experiment. At the top, a 20-mm. layer of K_2CO_3 was placed. In the unmixed charcoal,

Table I

COMPARISON OF CARBURIZATION EFFECT, USING SODIUM AND POTASSIUM CARBONATE AS ENERGIZERS, AT VARIOUS CARBURIZATION TEMPERATURES

Carbonate	Temp., °C.	Using 20% Carbonate-Charcoal Mixture		Using 10 mm. Top Layer of Carbonate on Charcoal	
		d_f	d_c	d_f	d_c
K_2CO_3	975	*2·3–2·5*	*0·9–1·1*	*2·3–2·5*	*1·1–1·2*
Na_2CO_3		2·3	0·9–*1·0*	2·5	1·1–*1·2*
K_2CO_3	950	2·1	*0·9*–1·0	*2·0–2·2*	*1·0–1·2*
Na_2CO_3		*1·9–2·0*	0·8	*2·1–2·2*	0·9–*1·0*
K_2CO_3	925	*1·5–1·6*	*0·5–0·6*	*1·5–1·7*	*0·4–0·6*
Na_2CO_3		1·7	0·5–*0·6*	*1·8*–1·9	0·5
K_2CO_3	875	1·0	*0·1–0·2*	*1·0–1·1*	0·2
Na_2CO_3		0·9	0·2	*0·9*–1·0	0·2
K_2CO_3	825	0·6–0·7	0	*0·5*–0·6	0
Na_2CO_3		0·5	0	*0·4*–0·5	0

Figures in italics refer to specimens at the bottom

of particle size 1–5 mm., were packed the standard specimens, and, in addition, 24 machine parts, in four layers. Each part had a volume of about 150 ml. After the ordinary heating cycle of 18 hr. at 930° C., the following results were obtained : $d_f = 1·5–1·6$ mm., $d_c = 0·8–0·9$ mm.

The final experiment was similar to the fourth, with a 10-mm. top layer of Na_2CO_3, representing about 28% by weight of the mixture. Results were :

$$d_f = 1·3–1·5 \text{ mm.}, d_c = 0·6–0·7 \text{ mm.}$$

In these experiments the accelerating effect of K_2CO_3 or Na_2CO_3 on carburization was equally noticeable in all parts of the box, the carbonate being absorbed by the charcoal. It may be concluded that those two carbonates, on heating to 925° C., rapidly spread from top to bottom. The minimum amount of carbonate required for full energizing action was not determined : the largest addition, about 33%, was obviously unnecessarily large. Using such quantities, on emptying the box, the charcoal particles in the bottom part were found to have sintered together.

Small-scale experiments were then carried out to determine the spreading powers of K_2CO_3 and Na_2CO_3 at temperatures of 975° C., 950° C., 925° C., 875° C., and 825° C. The charcoal particle size was 1–3 mm. and the specimens were held for 20 hr. at each temperature.

The following conclusions may be drawn from the results quoted in Table I :

(1) Under these experimental conditions, K_2CO_3 and Na_2CO_3 have about equal energizing effect on carburization, possibly with a slight preference in regard to K_2CO_3 at the lower temperatures.

(2) The results are, on average, slightly better with the carbonate applied as a top layer than when it is mixed with the charcoal.

(3) Comparing top and bottom specimens, the spreading power is found to be sufficient for K_2CO_3 and Na_2CO_3 at all the temperatures used, except possibly at 825° C.

Spent Carburizing Mixtures

The experiments with larger boxes were continued, using, apart from one exception, the spent carburizing mixtures from the experiments described in the previous section, without any further addition. In each box seven well-distributed specimens were packed, and the same heating cycle as before, 18 hr. at 930° C., was used. The results of experiments 1, 2, 3, 5, and 6 in Table II confirm earlier observations[2, 3] that, on repeated use of carburizing mixtures without additions, the carburizing power gradually declines. Experiment 4 shows that a spent mixture does not regain its power by the addition of a layer of fresh mixture on top of it.

Spent Carburizing Mixtures with Admixed Additions

It seems unlikely that loss of energizer, under the conditions of heating employed, could be solely responsible for the decline in carburizing power of the mixture on repeated use, and the addition of 50 mm., or about 50%, of fresh charcoal on top of the mixture did not restore its power. Long series of repeated carburizing experiments were therefore carried out, starting with different carburizers, and each time replenishing the shrinkage that occurred with fresh admixed

Table II

CARBURIZING POWER OF SPENT CARBURIZING MIXTURES, USING SODIUM AND POTASSIUM CARBONATES AS ENERGIZERS

Experiment No.	Charge	Addition	d_f, mm.	d_c, mm.
1	Fresh charcoal	Layer of K_2CO_3, 12 mm. deep	1·5–1·6	0·8–0·9
2	Charge from Expt. No. 1	None	1·4–1·5	0·7
3	,, ,, ,, ,, 2	,,	1·3–1·4	0·6–0·7
4	,, ,, ,, ,, 3	Top layer of 50 mm. fresh charcoal, mixed with 23% of K_2CO_3	0·9–1·1	0·3–0·5
5	Fresh charcoal	Layer of Na_2CO_3, 10 mm. deep	1·3–1·5	0·6–0·7
6	Charge from Expt. No. 5	None	1·2–1·3	0·5–0·6
7	,, ,, ,, ,, 6	,,	0·9–1·0	0·4

Table III

CARBURIZING POWER OF A CARBURIZER CONSISTING OF CHARCOAL WITH A LAYER OF POTASSIUM CARBONATE ON TOP, REPLENISHED MAINLY BY 10% OF CHARCOAL, ON REPEATED USE

Expt. No.	Charge	Additions		Shrinkage, %	d_f, mm.	d_c, mm.
		Charcoal, %	Others*			
1	Charcoal, with layer of K_2CO_3, 12 mm. deep, on top	...	...	27	1·5	0·7
2	Charge from Expt. No. 1	Quantity equal to previous shrinkage	...	5·3	1·5	0·7
3	,, ,, ,, ,, 2	,, ,, ,,	...	3·8	failed	failed
4	,, ,, ,, ,, 3	,, ,, ,,	...	2·3	1·4	0·6
5	,, ,, ,, ,, 4	,, ,, ,,	...	2·1	1·2	0·5
6	,, ,, ,, ,, 5	5	...	1·8	1·3	0·5
7	,, ,, ,, ,, 6	10	...	2·0	1·4	0·5
8	,, ,, ,, ,, 7	10	...	3·8	1·4	0·5
9	,, ,, ,, ,, 8	10	...	4·1	1·2–1·3	0·5–0·6
10	,, ,, ,, ,, 9	10	Layer of K_2CO_3, 6 mm. deep	5·1	1·5	0·7
11	,, ,, ,, ,, 10	Quantity equal to previous shrinkage	...	4·8	1·5	0·7
12	,, ,, ,, ,, 11	10	...	5·9	1·6–1·8	0·8–1·0
13	,, ,, ,, ,, 12	10	...	3·7	failed	failed
14	,, ,, ,, ,, 13	10	...	3·7	1·6–1·7	0·8–0·9
15	,, ,, ,, ,, 14	10	...	7·2	1·4–1·5	0·5
16	,, ,, ,, ,, 15	10	Layer of K_2CO_3, 2·7 mm. deep	9·6	1·6–1·7	0·6–0·8
17	,, ,, ,, ,, 16	10	...	7·4	1·6	0·7–0·8
18	,, ,, ,, ,, 17	10	...	3·7	1·5–1·6	0·6–0·7
19	,, ,, ,, ,, 18	10	s	14·8	1·5–1·6	0·7
20	,, ,, ,, ,, 19	...	s	13	1·3–1·4	0·5–0·6
21	,, ,, ,, ,, 20	20	s	12	1·5–1·6	0·8
22	,, ,, ,, ,, 21	Quantity equal to previous shrinkage	s	12	1·8	1·0
23	,, ,, ,, ,, 22	,, ,, ,,	s	16	1·6	0·8–1·0
24	,, ,, ,, ,, 23	,, ,, ,,	s	14	1·6	0·8
25	,, ,, ,, ,, 24	,, ,, ,,	s	13	1·5–1·6	1·1–1·2
26	,, ,, ,, ,, 25	,, ,, ,,	s	16	1·5	0·7
27	,, ,, ,, ,, 26	,, ,, ,,	s	15	1·5–1·6	0·7–0·8
28	,, ,, ,, ,, 27	,, ,, ,,	s	11	1·5	0·7
29	,, ,, ,, ,, 28	,, ,, ,,	s	10	1·5	0·7–0·8
30	,, ,, ,, ,, 29	,, ,, ,,	s	10	1·4–1·5	0·7
31	,, ,, ,, ,, 30	,, ,, ,,	s	8	1·4	0·6–0·7
32	,, ,, ,, ,, 31	,, ,, ,,	s	8	1·4–1·5	0·6
33	,, ,, ,, ,, 32	,, ,, ,,	s	8	1·4	0·6
34	,, ,, ,, ,, 33	,, ,, ,,	s	10	1·5	0·7
35	,, ,, ,, ,, 34	,, ,, ,,	Layer of K_2CO_3, 3 mm. deep s	8	1·4	0·6–0·7
36†	,, ,, ,, ,, 35	,, ,, ,,	s	11	1·3	0·6–0·7
37‡	,, ,, ,, ,, 36	,, ,, ,,	Layer of K_2CO_3, 3 mm. deep s	24	1·4	0·6–0·7
38‡	,, ,, ,, ,, 37	,, ,, ,,	s	19	1·3	0·6–0·7
39	,, ,, ,, ,, 38	,, ,, ,,	s	10	1·4	0·7
40	,, ,, ,, ,, 39	,, ,, ,,	s	8	1·5–1·6	0·7–0·8
41	,, ,, ,, ,, 40	,, ,, ,,	s	10	1·5	0·7
42	,, ,, ,, ,, 41	,, ,, ,,	Layer of K_2CO_3, 3 mm. deep s	12	1·5	0·8
43	,, ,, ,, ,, 42	,, ,, ,,	s	12	failed	failed
44	,, ,, ,, ,, 43	,, ,, ,,	s	18	1·5	0·8

* s indicates steel dummies in the box † No Refractite luting ‡ No Refractite luting, no top plate

charcoal, or varying the additions in different ways according to the results obtained. The carburizers used were mixtures of charcoal and K_2CO_3, Na_2CO_3, or $BaCO_3$ respectively, and two proprietary carburizing compounds. All experiments were made in the laboratory furnace, four boxes (*see* Fig. 1*a*) containing three specimens, each being heated at a time. The standard heating cycle, 20 hr. at 925° C., was used.

Charcoal and K_2CO_3—In this series of tests, the charcoal was unwashed, and of particle size 1–3 mm. for experiments 1–17, 1–5 mm. for experiments 18–28, and 1–10 mm. for experiments 29–44. The results are given in Table III. The description 'failed' in this and subsequent tables signifies that the temperature control was faulty.

Experiments 1 and 2 show the full carburizing effect, but experiments 4 and 5 indicate a decline in carburization that may be related to the small amount of fresh charcoal added to compensate for previous shrinkage. The low shrinkage, about 2%, obviously indicates good sealing of the box, but is also a consequence of the small surface area of steel specimens being carburized. In the subsequent tests 6–9, therefore, the quantity of fresh charcoal admixed was raised to 5 or 10%, the excess spent mixture being thrown away : this stopped the decline in carburizing power, but did not restore it to its normal value. However, after compensating for the loss of energizer in the carburizer which was thrown away, by adding a layer of K_2CO_3 6 mm. deep in experiment 10, and 2·7 mm. deep in experiment 16, the results of experiments 10–18 were satisfactory.

To increase shrinkage without waste of material, from experiment 19 onwards, eight steel dummies, consisting of half-Charpy soft-steel impact specimens (10 mm. × 10 mm. × 27 mm.) were also packed in the box. At first, of course, the dummies absorbed carbon, but after being used repeatedly they served simply to reduce the ratio of carburizer volume to specimen surface area. Thus, the shrinkage and the amount of fresh charcoal added were automatically raised. The results of experiments 16–33 show that satisfactory carburization was invariably obtained simply by replenishing each time the volume of carburizer lost through shrinkage, with fresh charcoal well mixed with the spent carburizer. In experiments 30–33, the shrinkage declines slightly, falling to about 8%. The subsequent experiments 34–44 seem to indicate (*a*) that the amount of fresh charcoal added should not be less than a certain critical amount, here about 10%, and (*b*) that there is a small loss of energizer, probably by evaporation and possibly in handling. It is possible that the increased particle size of the charcoal added in experiments 28–44 is partly responsible for the slightly lower values of carburization depth.

Table IV

CARBURIZING POWER OF A CARBURIZER CONSISTING OF CHARCOAL WITH A LAYER OF SODIUM CARBONATE ON TOP, REPLENISHED MAINLY BY 10% OF CHARCOAL, ON REPEATED USE

Expt. No.	Charge	Additions		Shrinkage, %	d_f, mm.	d_c, mm.
		Charcoal, %	Others*			
1	Charcoal, with layer of Na_2CO_3 12 mm. deep, on top	...	...	26	1·5	0·7
2	Charge from Expt. No. 1	Quantity equal to previous shrinkage	...	4·6	1·5	0·7
3	,, ,, ,, ,, 2	,, ,, ,,	...	3·7	failed	failed
4	,, ,, ,, ,, 3	,, ,, ,,	...	2·0	1·4	0·6
5	,, ,, ,, ,, 4	,, ,, ,,	...	1·9	1·3	0·5
6	,, ,, ,, ,, 5	5	...	1·9	1·3	0·5
7	,, ,, ,, ,, 6	10	...	1·9	1·4	0·5
8	,, ,, ,, ,, 7	10	...	3·6	1·4	0·5
9	,, ,, ,, ,, 8	10	...	3·9	1·2–1·3	0·5–0·6
10	,, ,, ,, ,, 9	10	Layer of Na_2CO_3, 6·5 mm. deep	5·0	1·5	0·7
11	,, ,, ,, ,, 10	10	...	5·3	1·5	0·7
12	,, ,, ,, ,, 11	10	...	4·1	1·3–1·5	0·5–0·7
13	,, ,, ,, ,, 12	10	...	5·9	failed	failed
14	,, ,, ,, ,, 13	10	...	5·9	1·3–1·6	0·7–0·8
15	,, ,, ,, ,, 14	10	...	4·7	1·4	0·5–0·6
16	,, ,, ,, ,, 15	10	Layer of Na_2CO_3, 2·7 mm. deep	6·7	1·3	0·5–0·6
17	,, ,, ,, ,, 16	10	...	5·2	1·2–1·3	0·4
18	,, ,, ,, ,, 17	10	...	7·4	1·5–1·6	0·7–0·8
19	,, ,, ,, ,, 18	10	...	7·4	1·5–1·7	0·7–0·8
20	,, ,, ,, ,, 19	...	s	4·0	1·6–1·7	0·7–0·8
21	,, ,, ,, ,, 20	Quantity equal to previous shrinkage	s	10	1·6–1·7	0·9
22	,, ,, ,, ,, 21	,, ,, ,,	s	12	1·6–1·7	0·8–0·9

* s indicates steel dummies in the box

If the results in Table III are compared with the results of experiment 4, Table II, it is evident that the addition of 50% of fresh charcoal and K_2CO_3, placed on top of the spent carburizer, does not prevent the deterioration in carburizing power of the latter, whereas an addition of 10% or more of fresh charcoal well mixed with the spent carburizer restores its carburizing power completely so long as the amount of energizer present is sufficient. It must be concluded that, in heating through one or two carburizing cycles, the fresh charcoal loses a great part of its active surface area. This assumption agrees well with the large shrinkage found in experiments 1 and 2 (Table III). By mixing fresh charcoal in sufficient amount with the spent carburizer, the minimum charcoal reaction surface required for the maintenance of high CO content in the gas is provided, and good carburization results.

Charcoal and Na_2CO_3—Unwashed charcoal was used, of particle size 1–3 mm. in experiments 1–14, and 1–5 mm. in experiments 15–22. The results, which are given in Table IV, agree on the whole with those of the K_2CO_3 series of experiments, with which these experiments were run in parallel. Similar conclusions may be drawn on the effect of mixing a sufficient amount of fresh charcoal with the spent charge, and of occasionally replenishing the slight loss of carbonate.

Washed Charcoal and $BaCO_3$—The particle size of the washed charcoal was 1–3 mm. in experiments 1–14, and 1–5 mm. in experiments 15–21. The results are given in Table V. The $BaCO_3$ energizer, when mixed with washed charcoal, behaves like K_2CO_3 and Na_2CO_3 added to unwashed charcoal. With sufficiently large additions of fresh charcoal (about 10% of the charge), the spent mixture gives repeatedly good carburization if the slight loss of carbonate is occasionally replenished by mixing. This is shown in the results for experiments 10–21.

Unwashed Charcoal and $BaCO_3$—The particle size of the charcoal was 1–5 mm. in experiments 1–4, and 1–10 mm. in experiments 5–16. The results are given in Table VI.

In this series of experiments steel dummies were packed with the specimens in the box, and in consequence a high shrinkage was maintained. It was expected that the carburization results might be worse than those obtained for a mixture of washed charcoal and $BaCO_3$, because some constituent in the ash might interfere with the energizing action of the $BaCO_3$, the more so as the ash content of the carburizer rose with repeated use. However, no such effect was noticeable after eight experiments. In order to accelerate the effect, if any, a quantity of charcoal was burned in air over a gas burner. The combustion was incomplete, and the 'ash' formed had a volume of 6% of the charcoal burnt. This ash was added in experiments 9, 10, and 13. The increase in ash content of the carburizer caused by adding 3 ml. of ash would be the same as that caused by adding $100/6 \times 3$, *i.e.*, 50 ml. of charcoal (about 50% of the carburizer charge), which is the equivalent of the additions of charcoal that would be made in five experiments, the shrinkage being 10%. Thus the addition of 3 + 3 ml. of ash in experiments 9 and 10

Table V

CARBURIZING POWER OF A $BaCO_3$–WASHED CHARCOAL MIXTURE, REPLENISHED MAINLY BY 10% OF CHARCOAL, ON REPEATED USE

Expt. No.	Charge	Additions		Shrinkage, %	d_f, mm.	d_c, mm.
		Charcoal, %	Others*			
1	Charcoal, mixed with 40% of $BaCO_3$	...	...	25	1·5	1·7
2	Charge from Expt. No. 1	Quantity equal to previous shrinkage	...	3·8	1·5	0·7
3	,, ,, ,, ,, 2	,, ,, ,,	...	3·0	failed	failed
4	,, ,, ,, ,, 3	,, ,, ,,	...	1·8	1·4	0·6
5	,, ,, ,, ,, 4	,, ,, ,,	...	2·2	1·1–1·2	0·5
6	,, ,, ,, ,, 5	5	...	1·6	1·3	0·5
7	,, ,, ,, ,, 6	10	...	2·1	1·4	0·5
8	,, ,, ,, ,, 7	10	...	3·9	1·4	0·5
9	,, ,, ,, ,, 8	10	...	4·3	1·2	0·5
10	,, ,, ,, ,, 9	10	22% of $BaCO_3$ (mixed)	4·8	1·5	0·7
11	,, ,, ,, ,, 10	10	...	5·2	1·5	0·7
12	,, ,, ,, ,, 11	10	...	5·2	1·6–1·7	0·6–0·7
13	,, ,, ,, ,, 12	10	...	7·4	failed	failed
14	,, ,, ,, ,, 13	10	...	7·4	1·8–1·9	0·8–0·9
15	,, ,, ,, ,, 14	10	...	7·4	1·5–1·7	0·6–0·7
16	,, ,, ,, ,, 15	10	...	7·4	1·5	0·5–0·6
17	,, ,, ,, ,, 16	10	...	5·9	1·6	0·7–0·8
18	,, ,, ,, ,, 17	10	...	8·8	1·5	0·7–0·8
19	,, ,, ,, ,, 18	10	s	11·1	1·5–1·6	0·8
20	,, ,, ,, ,, 19	...	s	12·5	1·6	0·8–0·9
21	,, ,, ,, ,, 20	Quantity equal to previous shrinkage	s	12·0	1·6	0·7–0·8

* s indicates steel dummies in the box

would represent ten extra experiments in regard to contamination of the carburizer. Considering the reduced amount of fresh charcoal added in experiments 9 and 10, the carburization power is fairly well maintained up to and including experiment 12. This represents, as far as contamination is concerned, $12 + 10 = 22$ repeated experiments with charcoal additions only.

After 6 ml. of ash had been added in experiment 13, there was a definite deterioration in carburizing power, which was maintained at a lower level in the experiments that followed.

In comparing this series of experiments with the preceding one, using washed charcoal, it is not possible to state whether washing the charcoal is beneficial when the $BaCO_3$ is mixed with the charcoal to form the carburizer. In both series the carburizer can be used repeatedly, probably more than 12 times, with no addition other than that of at least 10% of fresh charcoal, and with occasional replenishing of the slight loss of carbonate.

The less favourable results obtained in the carburization experiments recorded above in which $BaCO_3$-coated specimens were heated in unmixed, unwashed charcoal, are probably attributable to some reaction between the coating and K_2CO_3 or some other constituent in the charcoal ash.

Proprietary Compound A—In the experiments recorded in Table VII, the charcoal added was unwashed, and the particle size was 1–5 mm. in experiments 1–6, and 1–10 mm. in experiments 7–21.

After the good results of the first four experiments, there was a gradual deterioration, which was checked and turned into an improvement in the last four experiments, by additions of compound *A* to compensate for shrinkage.

It would seem that this compound shrinks less than the charcoal mixtures experimented with earlier, possibly owing to coke being an ingredient; consequently, the amount of charcoal added was fairly small. This fact, and the gradual consumption of energizer, probably account for the deterioration in results. It may well be argued that a compound which is intended to be used for replenishing shrinkage need not contain as much energizer as one which is to be replenished with charcoal only.

Proprietary Compound B—The charcoal added was unwashed, and had a particle size of 1–10 mm. The results are given in Table VIII.

Comments on experiments 1–8, are the same as for the experiments with compound *A*. Experiments 9–14 show that the compound which has been used only once may be used for replenishment. Finally, experiments 15–20 demonstrate, although the results are not consistent, that fresh compound *B*, when added to compensate for shrinkage, maintains good carburizing power.

DISCUSSION OF RESULTS

Seal and Shrinkage

The poorer the seal, the greater is the shrinkage. In carburization experiments with a mixture of

Table VI

CARBURIZING POWER OF A $BaCO_3$–UNWASHED CHARCOAL MIXTURE, REPLENISHED BY CHARCOAL, ON REPEATED USE

Expt. No.	Charge	Additions		Shrinkage, %	d_f, mm.	d_c, mm.
		Charcoal, %	Others*			
1	Charcoal mixed with 40% of $BaCO_3$	...	s	32	1·5	0·7
2	Charge from Expt. No. 1	Quantity equal to previous shrinkage	s	20	1·2–1·4†	0·4–0·6†
3	,, ,, ,, ,, 2	,, ,, ,,	s	17	failed	failed
4	,, ,, ,, ,, 3	,, ,, ,,	s	16	,,	,,
5	,, ,, ,, ,, 4	,, ,, ,,	s	15	1·4–1·5	0·7
6	,, ,, ,, ,, 5	,, ,, ,,	s	12	1·6	0·7–0·8
7	,, ,, ,, ,, 6	,, ,, ,,	s	14	1·5–1·6	0·7–0·8
8	,, ,, ,, ,, 7	,, ,, ,,	s	12	1·6	0·8
9	,, ,, ,, ,, 8	8	3 ml. of charcoal ash (s)	10	1·4	0·6
10	,, ,, ,, ,, 9	8	,, ,, s	9	1·2–1·3	0·5
11	,, ,, ,, ,, 10	Quantity equal to previous shrinkage	s	10	1·4	0·6
12	,, ,, ,, ,, 11	,, ,, ,,	s	10	1·3–1·4	0·5–0·6
13	,, ,, ,, ,, 12	2	6 ml. of charcoal ash (s)	11	1·2	0·5
14	,, ,, ,, ,, 13	Quantity equal to previous shrinkage	s	11	1·2	0·5–0·6
15	,, ,, ,, ,, 14	,, ,, ,,	s	10	1·2	0·4–0·5
16	,, ,, ,, ,, 15	,, ,, ,,	2 g. of $BaCO_3$ (mixed) (s)	10	1·2–1·3	0·5–0·6

* s indicates steel dummies in the box
† Specimens coated with $BaCO_3$

charcoal and K_2CO_3 as carburizer, the shrinkage volume being each time made up with charcoal, the efficiency of luting and of employing a top plate as a sealing device is illustrated by the following results :

Whether Luted with Refractite	Top Plate	Shrinkage, %
Yes	Present	8–10
Yes	Absent	10
No	Present	11
No	Absent	19–24

Hence, a loose lid without efficient luting provides only a poor seal. There is some indication that the best carburization results were obtained when both precautions were taken.

Regeneration of Spent Carburizer

The results show that, for all the carburizers investigated—charcoal mixed with $BaCO_3$, K_2CO_3, or Na_2CO_3, and two proprietary carburizing compounds—it is not necessary to add fresh carburizer for regeneration. If the carburizer contains a suitable amount of energizer from the start, a great number of successive carburizing runs can be made, adding only charcoal, and occasional small amounts of energizer (say at every tenth run) provided that each amount of admixed charcoal exceeds about 10% of the carburizer volume. If boxes are well sealed, the parts to be carburized have to be sufficiently closely packed so that the appropriate minimum shrinkage is attained, largely through the consumption of carbon for carburizing. The ratio of steel surface area to carburizer volume should be large. The loss of energizer, under ordinary conditions of handling, is probably very small.

Comparison of Different Energizers

In the present investigation, which was mainly limited to a carburizing temperature of 925° C., $BaCO_3$, K_2CO_3, and Na_2CO_3 appear to be almost equally good as energizers when mixed with charcoal in the appropriate proportion. K_2CO_3 and Na_2CO_3 may be applied, with equally good and uniform results, as a layer on top of the charcoal charge ; $BaCO_3$ cannot be so applied, since it has very small spreading power. It can, however, be applied as a coating on the steel surface, using a suitable binding agent, provided the charcoal charge is either inherently free or is purified by suitable washing, from some constituent, probably K_2CO_3. Carburizers consisting of charcoal with 10% of $BaCO_3$ and K_2CO_3 together in the proportions 3/1, 1/1, and 1/3 gave good results, equal to those obtained when either carbonate was added alone.

Soot Deposit

It was invariably observed that steel specimens carburized at 925° C. in a mixture of charcoal and K_2CO_3 or Na_2CO_3, and cooled in the box in air, were black from a soot deposit, whereas specimens carburized in a mixture of charcoal and $BaCO_3$ generally had no deposit and were grey. Since all three energizers were about equally effective at 925° C. the soot deposit probably was not involved in the reaction at that temperature. It is possible that, as the equilibrium between gas and carbon changes towards higher CO_2 content on cooling, K_2CO_3 and Na_2CO_3 are more powerful catalysts for this reaction than is $BaCO_3$. The charcoal particles presumably are also covered with soot in such cases. There was a distinct

Table VII

CARBURIZING POWER OF COMPOUND *A*, REPLENISHED WITH CHARCOAL, ON REPEATED USE

Expt. No.	Charge	Additions: Charcoal	Additions: Others*	Shrinkage, %	d_f, mm.	d_c, mm.
1	Compound *A*	...	s	32	1·7–1·8	0·9
2	Charge from Expt. No. 1	Quantity equal to previous shrinkage	s	9·6	1·5–1·6	0·7–0·8
3	,, ,, ,, ,, 2	,, ,, ,,	s	5	1·5–1·6	0·8
4	,, ,, ,, ,, 3	,, ,, ,,	s	7	1·5	0·6–0·7
5	,, ,, ,, ,, 4	,, ,, ,,	s	7	failed	failed
6	,, ,, ,, ,, 5	,, ,, ,,	s	11·2	1·4	0·5
7	,, ,, ,, ,, 6	,, ,, ,,	s	7	1·4	0·6
8	,, ,, ,, ,, 7	,, ,, ,,	s	10	1·3	0·5
9	,, ,, ,, ,, 8	,, ,, ,,	s	7	1·3–1·4	0·5–0·6
10	,, ,, ,, ,, 9	,, ,, ,,	s	4	1·2	0·4–0·5
11	,, ,, ,, ,, 10	,, ,, ,,	s	6	1·4	0·5
12	,, ,, ,, ,, 11	,, ,, ,,	s	6	1·3–1·4	0·5
13	,, ,, ,, ,, 12	,, ,, ,,	s	8	1·2–1·3	0·5
14	,, ,, ,, ,, 13	,, ,, ,,	s	8	1·3	0·5
15	,, ,, ,, ,, 14	,, ,, ,,	s	10	1·2–1·3	0·5
16	,, ,, ,, ,, 15	,, ,, ,,	s	10	1·2	0·5
17	,, ,, ,, ,, 16	,, ,, ,,	s	8	1·1–1·2	0·4–0·5
18	,, ,, ,, ,, 17	...	Quantity of compound *A* equal to previous shrinkage s	10	1·1	0·4–0·5
19	,, ,, ,, ,, 18	...	s	8	1·2–1·3	0·6–0·7
20	,, ,, ,, ,, 19	...	s	12	1·4	0·7–0·8
21	,, ,, ,, ,, 20	...	s	8	1·4	0·7

* s indicates steel dummies in the box

smell of ammonia when a box containing charcoal to which K_2CO_3 had been added was opened, after cooling from a temperature of 925° C., to 200–100° C.

Changes in Carburizer on Repeated Use

The carburizer referred to in Table III was originally prepared by placing a 12-mm. layer of K_2CO_3 on top of the unmixed charcoal in the box. The K_2CO_3 was absorbed during the first heating. The density of the freshly prepared mixture was about 0·27 kg./l., that of the unmixed charcoal powder (of particle size 1–3 mm.) being 0·18 kg./l. After 40 heating cycles, with additions of fresh charcoal and a few replenishments of lost K_2CO_3, the density was found to be 0·7 kg./l. It may be assumed that the charcoal particles lose their projections in the repeated reactions, and thus settle more densely. The soot deposited on them apparently does not counteract this effect.

Conversion of CO_2 to CO in a N_2–CO_2 Mixture

The action of energizers in accelerating carburization might take place according to either of the following mechanisms :

(i) The regeneration of CO_2 to CO by reaction with charcoal alone, tending towards the equilibrium $CO_2 + C \rightarrow 2CO$ . . . (*a*). The regeneration is postulated to be slow as compared with the rate of continuous supply of CO_2 by the reaction γFe (low C) + $2CO \rightarrow \gamma Fe$ (higher C) + CO_2 . . . (*b*). Consequently, the composition gradient in the gas region surrounding the steel is flat and the surface where composition approaches equilibrium (*a*) is at a great distance from the steel surface. If the energizer catalyses reaction (*a*), the equilibrium surface will be established nearer to the steel surface, and the composition gradient in the surrounding gas will be steep, *i.e.*, the gas mixture reacting with the steel surface will have a higher CO content, provided the steel at the surface is not saturated with carbon, than it would have with no energizer present, and carburization will, in consequence, be accelerated.

(ii) The energizer may cause a reaction (*c*) that increases the CO/CO_2 ratio beyond the equilibrium ratio for reaction (*a*) for charcoal, and reaction (*c*) may proceed at a faster rate than reaction (*a*). A very high CO/CO_2 ratio would be established in the gas surrounding the steel, any soot deposited from this gas, according to the reversed reaction (*a*), being continuously consumed by reaction (*c*).

It was thought that experiments in which a gas containing CO_2 was passed at a steady, moderate rate through a layer of heated charcoal, and the CO_2 content of the outgoing gas was determined, might be useful in interpreting the reactions taking place in the stationary atmosphere of the box.

Experiments were therefore carried out in the following way. In a vertical porcelain tube, of 25 mm.

Table VIII

CARBURIZING POWER OF COMPOUND *B*, REPLENISHED WITH CHARCOAL, ON REPEATED USE

Expt. No.	Charge	Additions: Charcoal	Additions: Others*	Shrinkage, %	d_f, mm.	d_c, mm.
1	Compound *B*	...	s	24	1·7	0·8–0·9
2	Charge from Expt. No. 1	Quantity equal to previous shrinkage	s	14	1·5	0·7–0·8
3	,, ,, ,, ,, 2	,, ,, ,,	s	14	1·3–1·4	0·7
4	,, ,, ,, ,, 3	,, ,, ,,	s	8	1·2–1·3	0·6
5	,, ,, ,, ,, 4	,, ,, ,,	s	12	1·2	0·5
6	,, ,, ,, ,, 5	,, ,, ,,	s	5	1·2	0·4
7	,, ,, ,, ,, 6	,, ,, ,,	s	10	1·1–1·2	0·5
8	,, ,, ,, ,, 7	,, ,, ,,	s	10	1·1	0·4–0·5
9	Compound *B*	...	s	24	1·6	0·8–0·9
10	Compound *B*	...	s	25	1·5–1·6	0·8–0·9
11	Charge from Expt. No. 9	...	Quantity of charge 10 equal to previous shrinkage: s	10	1·3	0·6–0·7
12	,, ,, ,, ,, 11	...	s	5	1·4	0·7
13	,, ,, ,, ,, 12	...	s	5	1·5	0·7
14	,, ,, ,, ,, 13	...	s	10	1·5	0·7
15	Compound *B*	...	s	25	1·3–1·5	0·6–0·8
16	Charge from Expt. No. 15	...	Quantity of compound *B* equal to previous shrinkage: s	20	1·6	0·7–0·8
17	,, ,, ,, ,, 16	...	s	20	1·5	0·7
18	,, ,, ,, ,, 17	...	s	10	1·4	0·7–0·8
19	,, ,, ,, ,, 18	...	s	25	1·2–1·4	0·6–0·7
20	,, ,, ,, ,, 19	...	s	20	1·4–1·6	0·8

* s indicates steel dummies in the box

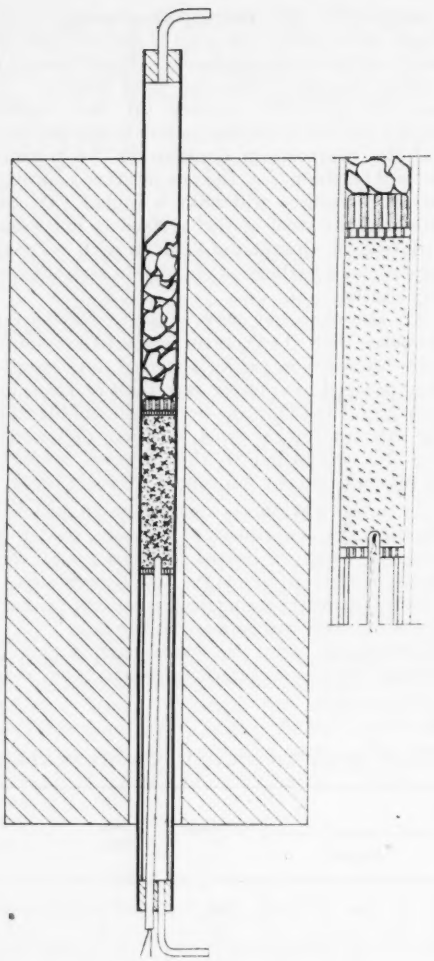

Fig. 2—Apparatus for gas-flow reaction experiments

inside dia. (Fig. 2), a layer of crushed charcoal, 120 mm. deep (10 g.) with or without additions, was placed between two perforated porcelain diaphragms. The tube was provided with a gas inlet at the top and an outlet at the bottom. It was placed in a furnace, as shown in Fig. 2, and in 3–4 hr. reached the desired temperature, as measured near the bottom of the charcoal layer. A slow stream of N_2 was passed through the tube during heating. On reaching the required temperature, the gas was changed to a mixture of 50% of N_2 + 50% of CO_2, its rate of flow being adjusted to a fixed value. The outgoing gas was passed through a sampling tube. After 10 min., this tube was replaced by another, and the gas collected at the end of the 10-min. period was analysed for CO_2 content. This procedure was repeated for a suitable number of 10-min. or longer periods, generally until, because of the consumption of a large part of the charcoal, the degree of conversion to CO was substantially diminished. The gas, before entering the reaction tube, passed through sulphuric acid. The chamber above the charcoal contained loose fragments of porcelain to assist in preheating the gas.

It was to be expected from the endothermic nature of the CO_2–charcoal reaction that the uniform temperature distribution in the charcoal layer would be disturbed by the reactive gas flow, apart from the possible effect of insufficient preheating. In one test, in which a temperature of 925° C. was reached while N_2 was slowly passing, the change to $N_2 + CO_2$, at a rate of flow of 0·5 l./min., reduced the temperature of the top end of the charcoal layer to 885° C., while the temperature at 90 mm. from the bottom was 900° C. However, since the temperature at the bottom (outlet) was maintained at 925° C. during all the experiments, it has been assumed that the results obtained are sufficiently accurate for comparison purposes.

Since, according to the results obtained by Fong and Ragatz,[3] the common carbonate energizers are rapidly and largely converted to oxide at the common carburizing temperatures, oxide was added in most of the present experiments with mixtures. It was finely powdered and intimately mixed with the charcoal. The results of these experiments are given in Table IX.

Generally, a fixed rate of flow, usually 0·5 l./min., was maintained in each experiment ; in experiments 17, 18, 19, and 20, however, variable rates of flow were tried, starting with a slow rate. A general feature observed is that the CO_2 content in the outgoing gas is lowest at the start, and gradually rises with time. Two causes may be responsible for this effect : (i) As the charcoal is consumed by the reaction, the vertical thickness of the layer is reduced and the reaction length is shortened ; (ii) the active surface area is likewise lessened (similar to the effect discussed in connection with repeated use of carburizers).

Experiments 1–3 (Table IX) show that the effect of the particle size of charcoal is small. The finest grade, 0·5–2 mm., appears to give somewhat lower CO_2 values, *i.e.*, better conversion.

In experiment 4, charcoal was used that had been heated for 100 hr. at 925° C. in a carburizing box with a good seal. The CO_2 value was constant at about 22% during the whole experiment : this represents the poorest conversion obtained in any of the experiments. Apparently, in this case, the consumption of some of the charcoal did not affect the result, which supports the proposed explanation of the need for fresh charcoal with large reactive surface area to restore the carburizing power of spent carburizers. A comparison of experiment 4 with experiment 2 shows that passing the N_2–CO_2 mixture through the tube for about 1 hr. at 925° C. is equivalent to heating charcoal in a closed box for 100 hr. at the same temperature. It is, of course, possible that, in the latter case, the condition of relative passivity may have been reached earlier.

Experiments 5 and 6 indicate that thorough washing of the charcoal gives better conversion.

In experiments 7–13, different substances have been added to the charcoal, in quantities that represent equal numbers of metal atoms. The substances can be arranged in three groups :

Table IX

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Table IX

AMOUNTS OF CO_2 PRESENT IN THE EXIT GAS AFTER VARIOUS INTERVALS OF TIME WHEN AN N_2–CO_2 MIXTURE IS PASSED THROUGH DIFFERENT CARBURIZERS

Expt. No.	Charcoal			Addition				Temp., °C.	Gas Flow-Rate, l./min.	Composition of Inlet Gas		Composition of Exit Gas—CO_2 Present, %									
	Weight, g.	Particle Size, mm.	Treatment	Material	Weight, g.	Weight, gram atoms of metal	Corresponding Weight of Carbonate (calculated), %			N_2, %	CO_2, %	after 10 min.	after 20 min.	after 30 min.	after 40 min.	after 50 min.	after 60 min.	after 70 min.	after 80 min.	after 90 min.	after 100 min.	Miscellaneous
1	10	0·5–2	..	..				925	0·5	50	50	14·2	18·0	17·3	17·8	17·5	16·9	16·0	16·1	18·9	24·7	
2	10	1–3	..	..				925	0·5	50	50	18·9	20·2	20·0	20·8	21·7	20·3	22·7	22·4	22·4	22·8	
3	10	3–7	..	..				925	0·5	50	50	16·9	17·7	20·3	20·9	21·2	21·8	21·6	21·6	22·0	22·9	
4	10	1–3	Annealed at 925° C. for 100 hr.	..				925	0·5	50	50	22·7	23·4	22·0	21·8	22·8	22·8	22·8	22·2			
5	10	1–3	Washed with dilute hydrochl. acid	..				925	0·5	50·5	49·5	10·2	11·8	12·4	12·8	14·0	15·0	16·8	17·9	20·5	22·4	
6	10	3–7		..				925	0·5	50	50	15·9	15·3	15·8	15·4	16·1	16·3	16·7	17·2	18·6	19·5	
7	10	1–3	..	NaOH	0·8	0·020	9·6	925	0·5	50	50	0·0	0·4	0·7	1·3	5·0	6·3	27·4				
8	10	1–3	..	KOH	1·1	0·020	11·9	925	0·5	50	50	0·0	0·5	0·6	1·0	2·4						
9	10	1–3	..	K_2CO_3	1·35	0·020	11·9	925	0·5	50	50	0·1	0·5	1·6	5·0	8·4						
10	10	1–3	..	MgO	0·8	0·020	14·3	925	0·5	50	50	16·0	17·9	18·9	19·8	19·2						
11	10	1–3	..	CaO	1·1	0·020	16·4	925	0·5	50	50	14·6	17·0	18·4	19·2	19·4	19·7	19·9	20·3	20·3	20·0	
12	10	1–3	..	SrO	2·0	0·020	22·1	925	0·5	50	50	17·3	17·4	21·2	22·2	22·0						
13	10	1–3	..	BaO	3·0	0·020	27·9	925	0·5	49·5	50·5	5·8	..	9·8	13·0	15·2	18·6	18·5	23·9	24·8	28·2	
14	10	1–3	..	BaO	1·0	0·006	10·4	925	0·5	50	50	6·2	10·6	13·0	12·7	14·4	16·2	17·8	20·2	23·0		
15	10	1–3	..	BaO	7·0	0·047	47·4	925	0·5	50	50	4·8	8·0	11·7	13·8	16·0						
16	10	1–3	Washed	BaO	3·0	0·020	27·9	925	0·5	50·5	49·5	6·7	7·5	8·7	10·1	12·2						
17	10	1–3	..	K_2CO_3	1·35	0·020	11·9	850	0·18	50	50	0·8	0·8	0·9								
									0·5	50	50				1·6	2·8	..	5·1				
18	10	1–3	..	K_2CO_3	1·35	0·020	11·9	800	0·18	50	50	4·2	4·4									
									0·083	50	50								2·6			3·3 (after 35 min.) 2·0 (after 110 min.)
									0·5	50	50											12·6 (after 120 min.) 13·9 (after 130 min.) 16·3 (after 140 min.)
19	10	1–3	..	BaO	3·0	0·020	27·9	925	0·06	50	50			0·2			0·2					
									0·09	50	50							0·4	0·2			
									0·5	50	50									15·9	16·8	19·6 (after 110 min.)
20	10	1–3	..	..				850	0·5	50	50	34·5	36·8	36·2	37·1	36·5						
									0·18	50	50						31·5					
									0·09	50	50							23·6				
									0·06	50	50										16·2	16·6 (after 85 min.)
									0·03	50	50											10·5 (after 130 and 160 min.)
									0·006	50	50											6·6 after 220 min. 7·6 after 280 min.

(i) Na- and K-compounds give, within the accuracy of the experiment, complete conversion at the start, and the charcoal was therefore rapidly consumed, a fact reflected in the rising CO_2 figures. K_2CO_3 gives the same complete conversion as does KOH at the start, but the CO_2 value rises more quickly for the former.

(ii) BaO gives the next best conversion, starting with a CO_2 figure of 5·8%, which rapidly increases. Varying the amount of BaO added between 1 and 7 g. does not appear to affect the CO_2 value noticeably. This corresponds to a variation in $BaCO_3$ of between 10 and 47%.

(iii) MgO, CaO, and SrO appear, in comparison with the results of experiment 2, to have a slight energizing action.

In experiments 17 and 18, lower temperatures, 800° C. and 850° C., were employed for a charcoal–K_2CO_3 mixture, and slower rates of flow were tried in order to approach more closely equilibrium for stationary conditions. In experiment 19, the effect of slower rates of flow was determined for a charcoal–BaO mixture at 925° C. Finally, in experiment 20 unmixed charcoal was subjected to a series of slow rates of flow at 850° C.

With the exception of the two slowest rates of flow in experiment 19, the CO_2 value decreases with decreasing rate of flow, showing that equilibrium has not been established. A comparison of equilibrium values is shown in Table X, in which equilibrium CO_2 contents are given, as calculated from data given by Austin and Day[5] for the reaction $C + CO_2 \rightleftharpoons 2CO$, to apply to the conditions as in the experiments described in this paper, *i.e.*, in the presence of N_2, originally 50% of the N_2–CO_2 mixture.

For unmixed charcoal at 850° C., the presumption (i) made on p. 255 is confirmed : the rate of reaction is very slow, and for a rate of flow of 0·006 l./min., the CO_2 value obtained, 6·6%, is very different from the equilibrium value of 2·18%.

However, for mixtures with K_2CO_3 or BaO, all CO_2 values for slow rates of flow are decidedly lower than the equilibrium values. Assuming that the latter are reasonably accurate, these results signify that the equilibrium in a charcoal–energizer mixture is not maintained according to the reaction $C + CO_2 \rightleftharpoons 2CO$, but according to some rapid reaction (*c*) in which the energizer takes part. Even considering the high activity of charcoal, it seems unlikely that the low CO_2 values obtained in experiments 7–9 and 19 represent equilibrium with charcoal. The equilibrium CO_2 value at 925° C. for charcoal mixed with suitable K-, Na-, or Ba-compounds appears to be very close to zero. The results for slow rates of flow in experiment 19 demonstrate that BaO, under stationary conditions at 925° C., belongs to the same group (i) of powerful energizers as K- and Na-compounds. Comparing these results with those of experiments 7–9 and 13–15, it may be concluded that Ba-compounds react more slowly with CO_2 than do K- and Na-compounds.

The inference is that in pack carburizing at the temperatures commonly employed, and using a powerful energizer, there is very little CO_2 in the gas in the box, as a result of the equilibrium demand, and of the rapid rate of the reaction (*c*). Further, the rate of carbon deposition from the supersaturated gas thus established is slow as compared with the rate of reaction (*c*). If reaction (*c*) involves conversion of oxide to carbonate, a reaction (*d*) with charcoal to regenerate oxide may be postulated, $BaCO_3 + C \rightarrow BaO + 2CO$, also proceeding at a rapid rate. The conclusions reached seem to agree well with the results and conclusions of Fong and Ragatz.[3]

The CO_2 produced by the carburizing reaction at the steel surface is rapidly reacted upon by the energizer present near that surface. A suitable quantity of $BaCO_3$, for instance, must be placed there, while none seems to be needed at a distance from the surface. K_2CO_3 and Na_2CO_3, by spreading, will be present near the steel surface even if not originally applied there.

Table X

COMPARISON OF THE PERCENTAGE OF CO_2 PRESENT IN THE EXIT GAS WHEN AN N_2–CO_2 MIXTURE IS PASSED THROUGH VARIOUS CARBURIZERS, WITH THAT PRESENT AT EQUILIBRIUM, AS CALCULATED FROM DATA GIVEN BY AUSTIN AND DAY[5]

Temp., C.	Expt. No.	Addition	Rate of Flow, l./min.	Quantity of CO_2 Measured, %	Quantity of CO_2 at Equilibrium, %
800	18	K_2CO_3	0·083 0·18	2·0–3·3 4·2–4·4	4·89
850	17	K_2CO_3	0·18 0·5	0·8–0·9 1·6	2·18
850	20	...	0·006 0·03	6·6 10·5	2·18
925	19	BaO	0·06 0·09	0·2 0·2–0·4	0·81

CONCLUSIONS

After studying the various ways in which the energizers K_2CO_3, Na_2CO_3, and $BaCO_3$ may be placed in the carburizer box with crushed charcoal and the objects to be carburized, two methods are found to give the same results as mixing charcoal and energizer :

(1) K_2CO_3 or Na_2CO_3 applied separately ; *e.g.*, as a layer on top of the charcoal. Those two energizers on being heated to the carburizing temperature rapidly spread out, forming a uniform mixture with the charcoal.

(2) $BaCO_3$, applied as a thin coating on the steel surface, preferably with the aid of a binding agent, such as lacquer. The coated specimens are packed in unmixed charcoal which has been washed thoroughly with dilute hydrochloric acid. As $BaCO_3$ has very small spreading power it remains where it is applied, exercising its energizing function near the steel surface ; apparently, the presence of an energizer is not required beyond a certain small distance from this surface. In carrying out the carburizing process with $BaCO_3$-coated steel objects, the presence of a small amount of K_2CO_3 in the charcoal or in the coating may interfere with the carburizing reaction in some unknown manner, so leading to poor results.

When a carburizer is used repeatedly, it is neces-

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sary to mix a minimum quantity of fresh crushed charcoal, about 10% of the total charge, with the spent carburizer each time it is re-used. A small amount of energizer should be added occasionally to compensate for the small evaporation and handling losses. When 33% of K_2CO_3 was originally added to a sample of charcoal, about 10% of fresh charcoal being admixed each time the test was repeated, 10% of K_2CO_3 added after ten runs maintained good carburization during the following ten runs with charcoal additions only. (If the energizer added is $BaCO_3$, it must be mixed with the carburizer.) Provided that the boxes are well sealed, the shrinkage of the carburizer in one carburizing operation may be so small that simply replenishing with charcoal will not satisfy the above condition of a minimum addition : if so, the steel objects are required to be more closely packed, thus increasing the ratio of steel surface to carburizer volume.

The decline in carburizing power of a powerful carburizer used repeatedly without any additions, noticeable after two or three carburizing cycles, is probably caused by a rapid loss in active surface area of the charcoal particles, and certainly not by loss of energizer.

It is found that the energizing power of certain substances, K-, Na-, and Ba-compounds, when a 1/1 N_2–CO_2 mixture is passed at fixed rates of flow through a layer of heated charcoal, with and without admixed substances, is reflected in a low percentage of CO_2 in the outgoing gas, particularly at slow rates of flow ; and, further, that charcoal reacts slowly with the CO_2. The CO_2 content of the gas, after it has passed slowly through a mixture of charcoal and an effective energizer, is found to be considerably lower than the equilibrium value for the reaction $C + CO_2 \rightleftharpoons 2CO$ at carburizing temperatures. It is concluded that another reaction in which the energizer takes part determines the composition of the gas in the carburizing box, both because of its low CO_2 value at equilibrium and its rapid reaction rate.

Acknowledgments

The present investigation originated from some observations made by S. Modin and T. Norén. The carburization experiments were carried out by S. Modin, N. Holm, N. Westerberg, and R. Söderman, and the gas–charcoal reaction experiments by K. Kuo, with the assistance of J. Stjärnström and S. Thomas, to all of whom thanks are due. The author particularly wishes to thank Mr. Kuo who calculated the equilibrium gas compositions and with whom fruitful discussions were held, and also to acknowledge his debt to the Government of Sweden Technical Research Council for a grant that made the investigation possible.

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Correspondence on the Paper—

EFFECT OF COOLING RATE AND COMPOSITION ON THE EMBRITTLEMENT OF WELD METAL*

By E. C. Rollason and R. R. Roberts

Dr. **K. Winterton** and Mr. **C. L. M. Cottrell** (British Welding Research Association, London) wrote : We were interested to read the account of the work of Rollason and Roberts describing an unusual form of cracking in mild-steel weld metal. This appears to be a new phenomenon, and the authors are to be congratulated on their speedy and thorough attack on the problem. Their findings were particularly interesting to us, since we have, in the last few months, observed similar instances of cracking in mild-steel weld metal during welding tests on heavy section low alloy Ni–Cr–Mo plate.

In one particular case, severe weld cracking was found in the test welds of a Reeve test. A 10-gauge electrode of the rutile-coated all-position type (E217 in the Institute of Welding—British Electrical and Allied Manufacturing Association's classification) was deposited at normal welding current (134 amp.), giving a fillet leg length of 0·20 in. The plates were 1½ in. thick, and of the following composition :

C, %	Mn, %	Ni, %	Cr, %	Mo, %
0·14	0·89	0·56	0·93	0·22

An example of the cracking obtained in this test is shown at low magnification in Fig. A, and part of the crack is shown at higher magnification in Fig. B. One feature of this phenomenon is that, in severe conditions, cracks can occur at random positions throughout the weld metal. At high magnification (Fig. B) it can be seen that the cracking assumes a peculiar branching form, so that three or more parallel fine cracks can sometimes be found. Though undoubtedly transcrystalline for most of their length, the cracks may follow the boundaries for short distances.

These cracks appear similar to those found in the hardened zone adjacent to the weld in alloy steel plate.

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Fig. A—General view of crack formation. Etched in 2% nital × 250

Fig. B—Branch cracking associated with oxide inclusions. Etched in 2% nital × 2000

Recent work has confirmed a theory put forward by Hopkin,[1] that cracking in the hardened zone is caused by diffusion of hydrogen from the weld metal, combined with the severe martensite transformation stresses ; the tendency to cracking increases with increased rate of cooling, either because of increased stresses or because of the increased retention of austenite.[2] The form of weld cracking already described may have a similar mode of formation ; more hydrogen would be present in the weld metal than in the hardened zone, but this is offset by the fact that the weld metal has a more ductile transformation product than the hardened zone. In the cracked weld mentioned above, the hardness value was 264 V.P.N. (average of three impressions with a 10-kg. load), this value being fairly high owing to the rapid cooling rate. Correspondingly, the structure shows a tendency to be acicular. Hardened-zone cracking has been observed with a hardness as low as 330 V.P.N., although the generally accepted safe limit is 350 V.P.N.

It is important to note that, whereas the observations of Rollason and Roberts refer to welds laid completely unrestrained, the test details given here refer to a severely restrained fillet weld. One of the cracks started from the root of the weld, which suggested that the external restraint played some part in its formation.

The cracking here reported was obtained with a fillet weld made between two plates 1½ in. thick, corresponding to a bead weld made on a single plate more than 2 in. thick. The cooling rate is severe, and is such that the temperature would reach 100° C. in less than 30 sec. from peak temperature. This is in agreement with the conditions Rollason and Roberts found necessary for the occurrence of cracking.

Figure B shows that the crack traverses in its path several cavities probably caused by the loss of inclusions during polishing. A similar phenomenon is apparent in Figs. 7 and 8 of the paper by Rollason and Roberts. These inclusions may act as centres for the accumulation of molecular hydrogen under pressure, and the cracking might be initiated from these points. The electrode used in the test gives a weld metal fairly rich in non-metallic inclusions.

The authors have referred to the possibility that nitrogen might be partly responsible for the cracking, although to a lesser extent than hydrogen. The evidence for this is not clear ; it appears that cracking was reduced in certain tests in which the welding was carried out under water. This involves a very different set of conditions, and makes comparison difficult. It is true that the nitrogen content is low under these conditions, but so, surprisingly enough, is the manganese content. The lower manganese content would considerably reduce the hardenability of the weld metal, and the authors in fact later refer to a marked increase of cracking with increasing manganese content.

AUTHORS' REPLY

Dr. **Rollason** (Murex Welding Processes, Ltd.) and Mr. **Roberts** (British Thomson-Houston, Ltd.) wrote : The contribution by Winterton and Cottrell provides a further illustration of the cracking of mild-steel welds owing to rapid cooling, and it is pleasing to note that they favour the hydrogen pressure theory for explaining the phenomenon. As they have mentioned, inclusions may act as centres for the accumulation of molecular hydrogen under pressure.

With regard to the importance of nitrogen as being partly responsible for promoting cracking, the results of other tests on welds made under water, but with varying manganese content, are given in Table A. The analyses were taken from the fissured welds, and the electrode coating was type E217.

Table A

TESTS ON UNDER-WATER WELDS

No.	Mn, %	N_2, %	Arc Fissures/ Section	Hardness, HD/10
9S	0·27	0·001	15	202
9A	0·76	0·001	30	242
9B	1·18	0·002	30	239

From these figures it is clear that, although the manganese content of the welds exceeds that plotted in Fig. 5 of our paper, the number of fissures is only 50% of those obtained in samples welded in air. The nitrogen content of these deposits is exceptionally low, which indicates that, whilst the effect of manganese is largely as pointed out (*i.e.*, to increase the number of fissures), nitrogen has an equally marked effect in increasing fissuring to the level obtained in the welds made in air.

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1. G. L. Hopkin : *Transactions of the Institute of Welding*, 1944, vol. 7, pp. 76–78.
2. M. W. Mallett and P. J. Rieppel : *The Welding Journal*, 1950, vol. 29, pp. 343-s–347-s.

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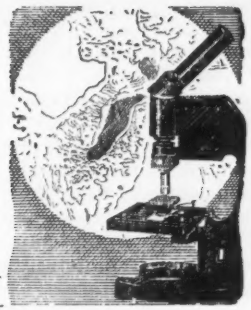

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

SYMPOSIUM ON STRESSES IN MOULDS

FOREWORD

In order to throw light on the basic causes of major cracking, work was designed to evaluate the stresses in an ingot mould during use. The practical work consisted of the simultaneous measurement of temperatures throughout the mould and of surface strains, but in order to evaluate the corresponding stresses certain data regarding the mechanical and physical properties of mould irons were required. These have been determined for a number of irons used for ingot moulds and considerable differences in tensile strength, Young's Modulus, and Poisson's Ratio were observed. Owing to these large differences, it was not possible with any degree of certainty to evaluate the actual stresses corresponding to the measured surface strains, but it has been shown that for the irons examined, there was an almost constant relationship between stress and strain, if the former was expressed as a percentage of the maximum tensile stress to fracture. Thus, it was possible to state that the stresses in the mould studied reached values of approx. 70% of the breaking stress. It was shown that this stress was of the same order as that of the ' endurance ' strength of the mould for a limited life of 150 cycles.

Growth phenomena have been studied for different irons, but it has been shown that growth occurs at temperatures at which the rate of relaxation of stress was exceedingly rapid. Growth, therefore, was unlikely to result in high stresses in the mould. Although there was some indication that irons having a high resistance to growth were those that gave high mould lives, it was not possible to relate the growth of the actual irons measured to the performance of the moulds from the same casts.

INTRODUCTION

THE ingot mould is an important item of expendable equipment in the steelworks. Its provision and maintenance account for several shillings per ton in the price of the steel ingot. At a conservative estimate of average mould consumption at 35 lb./ton of steel, the annual cost of moulds in this country, allowing for sale of scrap moulds, is about £4,500,000. It is one of the tasks of the Ingot Moulds Sub-Committee to improve the performance of ingot moulds and thus reduce this expenditure. A reduction throughout the industry of only 5% in mould consumption would correspond to a total saving of about £225,000 per annum.

Since its inception in 1934, this Sub-Committee has collected and analysed many data on the composition, manufacture, and conditions of use of moulds, and their relation to mould performance, and valuable conclusions on a considerable number of points have been reached. Early in its life, however, the Sub-Committee realized that the collection and correlation of works data and the execution of direct works experiments were not enough, and that fundamental data were needed if the design of moulds was to be put on a scientific basis.

One of the chief reasons for the rejection of ingot moulds is cracking, and it was primarily to investigate the basic causes of cracking that the Stresses in Moulds Panel was set up in 1939. The first constitution of the Panel was :

Mr. G. STANFIELD (*Chairman*)	Brown-Firth Research Laboratories
Mr. A. G. HOCK	Workington Iron and Steel Co.
Mr. R. H. MYERS	British Iron and Steel Federation
Mr. D. A. OLIVER	Wm. Jessop and Sons, Ltd.
Dr. J. G. PEARCE	British Cast Iron Research Association
Mr. T. F. RUSSELL	English Steel Corporation, Ltd.
Mr. J. WOOLMAN	Brown-Firth Research Laboratories.

After the untimely death of Mr. Stanfield in 1942, Mr. Woolman became Chairman of the Panel, which also co-opted Mr. T. Land, then of Wm. Jessop and Sons, Ltd., who resigned later owing to ill health. The present constitution is :

Mr. J. WOOLMAN (*Chairman*)	Brown-Firth Research Laboratories
Mr. N. H. BACON	Steel, Peech and Tozer
Mr. G. T. HARRIS	Wm. Jessop and Sons, Ltd.
Mr. A. G. HOCK	Workington Iron and Steel Co.
Mr. J. W. GRANT	British Cast Iron Research Association
Mr. J. E. RUSSELL	English Steel Corporation, Ltd.

Paper SM/BA/36/50 of the Ingot Moulds Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 30th August, 1950.

On several occasions the Panel has also had the services of Mr. W. C. Heselwood, of The United Steel Companies, Ltd., Research and Development Department.

The Panel, now called the Stresses in Moulds Group, began its work by a study of temperature distribution in mould and ingot during and after casting. The Ingot Moulds Sub-Committee had already reported[1] tests in which the temperature gradients at various points in the wall of a 10-ton slab mould were determined. In a paper[2] published in 1941, Russell examined the known formulæ for the mathematical determination of temperature distribution in moulds, and worked out a number of practical examples, using the method developed by Saitô.[3] In the absence of complete data and of a knowledge of initial temperature gradients in, and subsequent movement of, the liquid steel, rather sweeping assumptions had to be made. Nevertheless, with a suitable choice of constants, reasonable agreement between calculated temperatures and those found by experiment on a number of moulds was obtained, except for points near the inner faces of the moulds. Russell considered that the possibility of deriving more exact formulæ for the determination of temperature distribution was remote.

In a paper published in 1943, Land[4] calculated the thermal stresses which would be set up in ingot moulds under certain conditions. In the first section of the paper, the stresses were obtained for long cylindrical moulds of $93\frac{3}{8}$ cm. ($36\frac{3}{4}$ in.) internal dia., the physical properties of which were assumed to be independent of temperature and stress, and the deformation to be entirely elastic. With these assumptions, the stresses set up at the outer surface of the mould were shown to be roughly equal to the ultimate tensile strength of the ingot mould iron (assumed to be about 10 tons/sq. in.) and to reach their peak within a few minutes of casting, subsequently falling away. The stresses in a very thin mould (mould-weight (M)/ingot-weight (I) ratio 0·306) would exceed those in one of more normal wall thickness (M/I ratio 1·014) by about 20%.

In the second section of Land's paper, the occurrence of plastic deformation and the variation of the physical properties of the mould material were taken into account, using assumed stress/strain curves, and considerably lower surface stresses were obtained. For a mould with an M/I ratio of 1 the stress was about 4 tons/sq. in., and for the thin-walled mould with M/I ratio 0·306 the stress was 4·3 tons/sq. in. Land pointed out that this difference between the stresses occurring with the two wall thicknesses was likely to be accentuated by the creep occurring in the hot parts of the mould, since with the thicker-walled mould a much greater period elapses before the stress reaches its maximum. The actual stress occurring would be less than that calculated, the difference being greater with the thick-walled mould than with the thin-walled one. The use of different rates of loading when obtaining high-temperature stress/strain curves on ingot mould irons would thus be necessary if accurate calculations were to be made.

Stresses in non-circular moulds were next considered, and although a quantitative derivation was not possible mathematically, Land advanced a theory to show that the hoop stresses would probably not vary by more than 20% around the periphery of the mould on any one horizontal plane, and that they should not be very different from those occurring in circular moulds. Axial stresses would be mainly dependent on the temperature differences through the thickness of the wall, and would thus be greater in the middle of the faces of the mould than at the corners. It was estimated that in a circular mould the hoop stresses at the free end would be increased by about 25% because of end effects. For non-circular moulds the effect was too complicated for calculation. Land also outlined the experimental work that would be necessary to put the theoretical calculation of stresses on a firmer basis and to check it experimentally.

For the first of these, a knowledge of the following properties of mould irons was needed :

(i) The true stress/strain curves of representative irons at temperatures up to 800° C. These should be for the materials in tension up to 500° C., and in compression from 300° C. to 800° C. For the higher temperatures the effect of rate of loading on the curves would need to be known

(ii) Poisson's ratio at the stresses and temperatures laid down for the mechanical tests

(iii) The coefficient of thermal expansion at temperatures up to 800° C.

For the experimental checking of the calculated stresses, measurements of expansion of the mould surface in at least three directions, with the measurement of surface temperature, would be necessary.

Almost since its inception, the work of the Group has been hampered by the pressure of wartime and post-war work of greater urgency, and no papers have been published since that by Land. It was early realized that the quickest method of obtaining an idea of stresses present in test moulds was by the second approach suggested by Land, and that the first essential was to obtain the mechanical and physical data on the mould irons necessary for the subsequent calculation. As the work progressed, difficulties became apparent owing to the variation of properties of the mould irons, and tests on several samples of differing analyses were necessary before sufficient data had been accumulated. Only a part of the work suggested by Land for his first approach has been carried out, but certain auxiliary mechanical tests, to determine, for instance, the effects of repeated stress or variation of the rate of loading, have been made. It was also thought that an investigation into the growth properties of ingot mould irons might be useful, since the different parts of any mould reach different temperatures in use and are thus subject to different rates of growth. This non-uniform growth might set up stresses quite apart from those occurring during the usage of the mould, and a knowledge of its magnitude and likely effects was desirable. More recently, however, it has been shown that relaxation at the temperatures at which growth occurs is very rapid, so that stresses resulting from differential growth cannot assume serious proportions.

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MECHANICAL PROPERTIES OF INGOT MOULD IRONS

By J. W. Grant, A.M.I.Mech.E.

SYNOPSIS

Mechanical tests have been carried out on ingot mould irons at temperatures up to 800° C. to provide stress/strain data from which stresses in ingot moulds may be calculated, and to investigate the behaviour of these materials under the type of stress and strain conditions to which an ingot mould might be subjected during its life. Transverse, tensile, compression, creep, and 'endurance' tests were carried out.

The weaker irons gave the greatest extensions for a given load, the magnitude of the extensions being greater at 400° C. than at room temperature, but there was no change in ultimate tensile stress.

In the endurance tests at 400° C., failures occurred after less than 100 repeated applications of less than 80% of the ultimate tensile stress.

During the life of an ingot mould, the outside surface reaches a temperature of over 600° C. before cooling and being re-used. When a test piece was permanently deformed by straining and was then subjected to the same temperature cycle, the same stress/strain curve as in the first test was obtained. There was evidence, however, of a damaging effect causing the iron ultimately to break at a lower stress and at a lower total elongation than if it had not been heat-treated in this manner.

THE usefulness of data on the mechanical strains which exist in an ingot mould as an ingot is teemed, depends upon the ability to relate these to the properties of the material. To do this it is necessary to know the stress/strain–temperature–time characteristics of ingot mould irons so that the measured mechanical strains can be converted to stresses. The calculation of stresses, however, is complicated by their varying rate and magnitude, and by the change in temperature during the heating-up of the mould, and, perhaps of lesser importance, during the cooling-down after stripping.

The object of the work carried out at the British Cast Iron Research Association was to provide data about the strength and strain properties of ingot mould irons, which could be used to estimate the stresses existing in an ingot mould and perhaps to elucidate the causes of failure by major cracking. Ten batches of test blocks were made by six firms of ingot-mould manufacturers in standard and modified mixes to provide material on which to carry out tests between room temperature and 800° C. The tests included transverse, deflection, and tensile tests at room temperature on as-cast, stress-relieved, and annealed bars; stress-to-rupture tensile tests at temperatures up to 800° C.; tensile tests with stress/strain determinations at room temperature and at 400° C.; compression tests at room temperature; tensile endurance tests at room temperature and at 400° C.; and two short-time creep tests and a growth test at 400° C.

INGOT MOULD IRONS USED

The blocks of ingot mould iron supplied by the manufacturers were of 6 in. × 4 in. section cut longitudinally into bars approx. 2 in. square × 30 in. long. They were generally cast from each manufacturer's standard mixture but, to cover a range of compositions, in two cases secondary hematite pig iron was used, and in a third case a phosphorus addition was made. The descriptions and chemical analyses of the ten irons used are given in Table I. The total carbon estimations were made on solid pieces approx. $\frac{1}{8}$ in.

Paper SM/BA/158/49 of the Ingot Moulds Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 30th August, 1950.

Mr. Grant is on the staff of the British Cast Iron Research Association.

Table I

DESCRIPTION AND CHEMICAL ANALYSES OF IRONS USED

Ingot Mould Iron No.	Manufacturer	Description	Chemical Analyses,* %				
			Total C	Si	Mn	S	P
1	*A*	Standard	3·71	1·53	0·72	0·071	0·057
2	*A*	Standard + 10% secondary hematite	3·61	1·50	0·64	0·074	0·062
3	*A*	Standard + 25% secondary hematite	3·52	1·32	0·61	0·082	0·066
4	*A*	Raised phosphorus (0·21%)	3·84	1·61	0·66	0·065	0·21
7	*B*	Standard	3·86	1·37	0·98	0·063	0·116
8	*B*	,,	4·06	1·13	1·03	0·064	0·131
9	*C*	,,	4·27	1·81	0·88	0·053	0·037
12	*D*	,,	3·82	1·49	0·43	0·086	0·076
13	*E*	,,	4·29	1·85	0·83	0·054	0·047
14	*F*	,,	4·01	2·07	1·03	0·051	0·036

* By spectrochemical analysis traces of Ni, Cr, Cu, Sn, As, Ti, and V were found but there was no W, Co, Zr, Pb, or Al

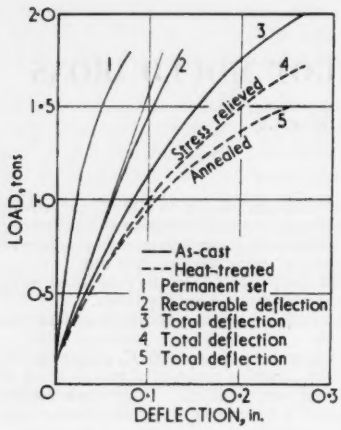

Fig. 1—Transverse load/deflection curves for iron No. 8

square × 2 in. long, and for the remaining estimations drillings were used.

Transverse, tensile, and impact tests were carried out at room temperature on test bars (*a*) in the as-cast condition, (*b*) after stress-relieving at 600° C. for 24 hr. followed by slow cooling in the furnace, and (*c*) after an annealing treatment of 28 days at 720° C. Pilot annealing tests were carried out on iron No. 8 which had the lowest silicon and highest manganese contents. The microstructure of the as-cast material consisted of medium- and coarse-flake graphite in a matrix of pearlite containing a little free ferrite associated with the graphite flakes. Pilot specimens annealed at 720° C. for 24 hr., 4 days, 7 days, and 28 days showed a progressive spheroidization and decomposition of the pearlite, but even after 28 days the decomposition was not complete. The microstructure of the sample annealed for 28 days at 720° C. is illustrated in Fig. 2. There was partial spheroidization of the pearlite in the sample which had been stress-relieved at 600° C. The Brinell hardness of the as-cast, stress-relieved, and annealed samples of iron No. 8 was 132, 118, and 85 respectively.

Table II

DATA FROM DILATATION TESTS

Condition	Average Coefficient of Expansion, 15–740° C., × 10⁻⁶	Temperature of Critical Transformation, ° C.	
		Heating	Cooling
As-cast	14·5	767	702
Stress-relieved	14·4	767	711
Annealed	13·9	767	702

Data obtained from dilatation tests carried out on the three samples are given in Table II.

The transverse tests were carried out by a set and deflection method on a 24-in. span, the bars being machined approx. 1·8 in. square. A small initial load of 0·1 ton was applied to the centre of the bar and a dial gauge was used for measuring the deflection set to zero. A load of 0·2 ton was then applied, the deflection measured, the load reduced again to 0·1 ton, and the amount of permanent deflection noted from the dial gauge. This procedure was repeated with increasing loads up to fracture so that for each load a value was obtained for total deflection and permanent set. The difference between the total deflection and permanent set represents the recoverable or 'elastic' deflection. The three curves, total, recoverable, and permanent deflections for the as-cast, together with the total deflection curves for the stress-relieved and annealed bars of iron No. 8 are illustrated in Fig. 1. The recoverable deflection curves for the three bars of each iron were almost straight at the lower loads and it was from the slopes of these parts of the graphs that a value was calculated for the 'apparent' modulus of elasticity. The expression 'apparent' is used because at no stage does the iron behave perfectly elastically and it therefore has no true modulus of elasticity but the derived figure is an index of the relative rigidity of the irons at low stresses.

Tensile test pieces having a 0·798-in. dia. ($\frac{1}{2}$ sq. in. in area) and 2-in. gauge length were machined from the broken halves of the bars tested in transverse. As with ordinary cast irons, the ratio of transverse

Table III

RESULTS OF MECHANICAL TESTS AT ROOM TEMPERATURE

Ingot Mould Iron No.	Transverse, tons/sq. in.			Deflection, in.			Tensile Strength, tons/sq. in.			Modulus of Elasticity (from transverse test) × 10⁶, lb./sq. in.		
	a	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
1	12·0	12·3	9·1	0·30	0·28	0·30	6·7	6·0	5·3	9·0	8·0	8·7
2	17·1	14·7	10·6	0·30	0·30	0·28	8·4	7·1	5·8	10·6	10·2	10·1
3	17·7	16·7	11·4	0·32	0·38	0·30	10·3	10·0	5·8	10·6	10·0	11·2
4	11·9	13·9	10·9	0·30	0·29	0·34	7·7	6·7	5·7	10·0	7·8	9·0
7	12·2	10·8	7·4	0·27	0·25	0·25	5·2	5·2	3·7	7·3	9·6	7·8
8	10·5	10·3	8·4	0·24	0·27	0·26	4·8	5·0	4·0	7·9	7·8	7·6
9	11·4	11·4	7·6	0·29	0·30	0·19	5·7	5·8	4·3	9·5	10·2	8·0
12	15·2	13·9	9·0	0·33	0·34	0·21	7·7	7·9	5·2	10·5	10·3	10·1
13	11·8	12·2	8·9	0·28	0·30	0·23	6·0	5·8	4·2	7·8	8·9	8·0
14	10·9	11·0	8·5	0·32	0·31	0·28	5·7	5·6	4·0	7·5	7·3	7·6

a = as-cast ; *b* = stress-relieved ; *c* = annealed

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Fig. 2—Microstructure of iron No. 8 after annealing at 720° C. for 28 days
Etched in 4% picric acid (Reduced by 7/10 linear in reproduction) × 60

Fig. 3—Microstructure of iron No. 12

Fig. 4—Broken tensile test bar of iron No. 12, tested at 800° C., showing circumferential cracks along gauge length

Fig. 5—Microstructure of longitudinal section through cracks illustrated in Fig. 4, showing internal cracks in addition to those at the surface. Unetched. (Reduced by 7/10 linear in reproduction) × 7

Fig. 6—Iron No. 12, tested at 800° C., showing oxide penetration and decarburization at a surface crack. Etched in 4% picric acid. (Reduced by 7/10 linear in reproduction) × 60

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(a)

(b)

Fig. 7—Crack-like appearance of micro-specimen of an ingot mould iron : (*a*) Incorrectly polished ; (*b*) the same area correctly polished. Both etched in 4% picric acid. (Reduced by 7/10 linear in reproduction) × 600

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to tensile strength was about 1·8 : 2·2 but the level of strength was low owing to the coarseness of the structure. The ' apparent ' modulus of elasticity, also in accordance with the behaviour of ordinary cast irons, tended to rise with tensile strength.

The results of transverse, deflection, and tensile tests and the modulus of elasticity are given in Table III.

All the microstructures in the as-cast condition consisted of medium-to-coarse flake graphite in a pearlitic matrix sometimes containing a small amount of ferrite. Areas of phosphide eutectic were present in quantities appropriate to the phosphorus contents of the irons. Figure 3 is typical of the microstructures in general.

STRESS-TO-RUPTURE TESTS AT TEMPERATURES UP TO 800° C.

As parts of the outer surfaces of the ingot moulds were known to become red-hot during use, the first tests at elevated temperatures were carried out to determine the ultimate tensile stresses of nine of the ingot mould irons under a constant rate of loading at temperatures up to 800° C. The tests were carried out in a 50-ton hydraulic universal testing machine using a minor capacity chart of 10 tons. The tensile test piece, shown in Fig. 8, had a 1·128-in. dia. (1 sq. in. area) and a 3½-in. parallel gauge length. The test pieces were screwed into heat-resisting holders which were provided with spherically seated shackles.

To the centre and at both ends of the 3½-in. parallel portion of the test piece were attached base-metal thermocouples. Platinum/platinum–10% rhodium couples were used for tests at 800° C. The test piece was heated by a wire-wound furnace having three separate windings along its length, each of which could be independently controlled through a variable transformer. The furnace was regulated so that the temperature difference between the three couples did not exceed 3° C. for temperatures up to 600° C., and 5° C. for the tests at 800° C. The average temperature of the three couples was controlled to within ± 1° C. up to 600° C. and ± 2° C. at 800° C. The test piece was maintained at the temperature of the test for one hour before applying the breaking load. For all tests the specimen was heated to the required test temperature at a rate of 280° C./hr.

Tensile tests were carried out at room temperature, and at 300°, 400°, 600°, and 800° C., and in each case the rate of stressing was 1 ton/sq. in./min. The ultimate tensile strengths are given in Table IV.

Table IV

ULTIMATE TENSILE STRENGTH AT VARIOUS TEMPERATURES

Ingot Mould Iron No.	Room Temp. (15° C.)	300° C.	400° C.	600° C.	800° C.
1	6·7	6·5	5·9	4·2	1·3
2	9·2	9·2	8·6	3·3	1·5
3	11·2	9·8	9·4	4·5	1·6
4	7·1	7·7	7·2	3·6	1·3
7	5·3	5·7	5·8	2·8	1·0
9	5·1	4·6	4·8	2·3	1·1
12	6·2	8·0	6·9	3·5	1·5
13	6·5	5·4	5·3	2·7	1·2
14	5·3	5·4	4·9	2·6	1·0

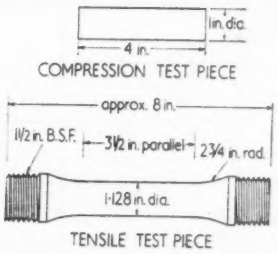


Fig. 8—Dimensions of tensile and compression test pieces

In conformity with the general behaviour of cast iron in short-time high-temperature tests the nine ingot mould irons maintained their strength up to 400° C. With the exception of No. 1, the strengths at 600° C. were only 50% of those at 400° C., and at 800° C. the strengths of all the irons were between 1 and 2 tons/sq. in. During the testing it was apparent that all the irons were stretching rapidly at 600° and 800° C.

The test pieces broken at 600° and 800° C. showed many circumferential cracks of varying depths at points along the gauge length. Figure 4 illustrates a deep crack and two finer cracks on the broken half of specimen No. 12, tested at 800° C. These cracks had formed in addition to the main one at which fracture had eventually occurred. Macro-examination of a longitudinal section showed that these surface cracks extended a long way into the metal ; some internal cracks, shown in Fig. 5, were also observed. Oxide penetration and decarburization were observed in several of the external cracks (*see* Fig. 6).

Inter-Graphitic Cracking

The presence of cracks in these test pieces led to some speculation about the occurrence of cracks in an iron before it is stressed. One observer claimed to have detected ' inter-graphitic cracking ' in ingot mould irons and to be able to place the irons in order of severity. Some suspected cases of inter-graphitic cracking were therefore submitted for careful examination but in no cases were any cracks observed.

The lines in the microstructure, which had been regarded as cracks, were dou ss caused by the burnishing-over of the metal su nding the graphite flakes owing to faulty polishi . The crack-like appearance of a micro-specimen, which has been polished purposely to burnish the metal, is illustrated in Fig. 7*a*. Figure 7*b* shows the same specimen after polishing correctly ; all the ' cracks ' have either been replaced by flakes of graphite or have been entirely eliminated. Furthermore, the samples which were claimed to possess the greatest amount of cracking were found also to contain the greatest amount of ferrite surrounding the graphite flakes, a constituent which, by its relatively soft nature, is more prone to burnish.

STRESS/STRAIN TESTS AT ROOM TEMPERATURE AND AT 400° C.

The ideal method of estimating the stresses existing in the surface of an ingot mould would be to reproduce

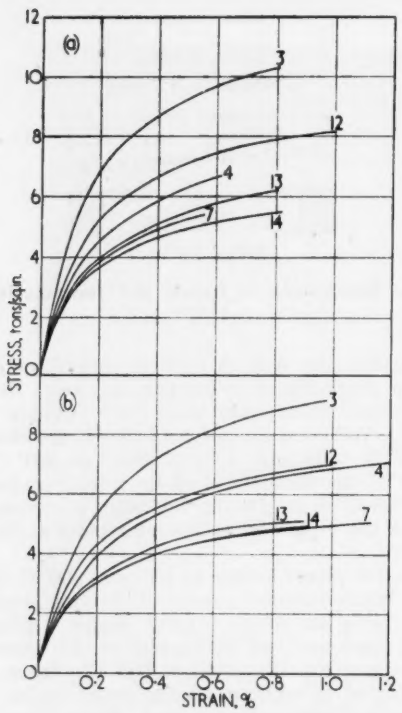


Fig. 9—Tensile stress/strain curves for various irons : (*a*) At room temperature, (*b*) at 400° C.

the same temperature change in the tensile test piece as in the mould surface and to measure the stress required to produce the same strain. The practical difficulties, however, make this impossible. The temperature changes are very rapid and irregular, 400° C. being reached in less than 15 min. There may be a large error in compensating for the temperature changes of the strain-measuring device on the mould and on the test piece, and it is not possible to measure the expansion of the mould surface when the temperature exceeds about 400° C. because of the detrimental effect of heat on the measuring devices. It was felt, however, that if the stress/strain properties were known for a number of ingot mould irons at room temperature and at 400° C., the measured strains could be converted to stresses fairly accurately by interpolation.

The stress/strain properties to fracture were therefore determined at room temperature and at 400° C., at a constant rate of loading of 1 ton/sq. in./min., on ingot mould irons Nos. 3, 4, 7, 12, 13, and 14. The tensile test pieces had the same dimensions as those used in the previous tests and the extension was measured over a 3-in. parallel gauge length. The heat-resisting legs of the extensometer protruded below the furnace, where their relative movements were indicated on dial gauges reading to 0·0001 in. The breaking stresses and total extensions are given in Table V, and the stress/strain curves at room temperature and at 400° C. in Fig. 9.

In general the figures for ultimate tensile strength were in fairly good agreement with those obtained in the previous tests at the same temperatures (*see* Table IV). The stronger irons Nos. 3 and 12 were more rigid, *i.e.*, they stretched less for a given load than the weaker irons Nos. 4, 13, 7, and 14. This relationship between the stress/strain curve and ultimate strength was generally true for all irons and for both temperatures. Also, although there was little difference between the ultimate tensile strengths at room temperature and 400° C., the stress/strain curve of each iron at the higher temperature lay to the right of the room-temperature curve. The total elongation was always greater at the higher temperature but it bore no relation to the strength or to the general slope of the stress/strain curve.

Loading and Unloading Cycles of Stress

Cast iron, unlike an elastic material such as steel, does not obey Hooke's Law of stress/strain proportionality. Even at low stresses there is always a certain amount of permanent set after a cast-iron test piece has been loaded and unloaded (*see* Fig. 10). Upon loading a second time the stress/strain curve will be entirely different from the original, a difference which will depend upon the characteristics of the iron and the magnitude of stress reached during each loading.

The original stress/strain curve could be used to convert mould-surface strain to stress for the teeming of the first ingot, but during the teeming of the second and subsequent ingots the stress/strain curve of the iron would be different as it would have already been plastically strained and given a permanent set. A series of tests was therefore carried out to show the effect of unloading and reloading at nominal stress levels. The occurrence of stresses during the second use of an ingot mould is not, however, a simple comparison with the immediate reloading of a tensile bar at constant temperature. Before a mould is used for a second time it may have reached a temperature of 600–700° C. and cooled to room temperature. This heating and cooling cycle, as will be shown later in this paper, changes the condition of the iron so that in certain circumstances it has its original stress/strain properties restored.

The tests were carried out on irons Nos. 3, 4, 7, and 12 at room temperature and at 400° C. To the 3-in. parallel gauge length was attached a mirror-type

Table V

BREAKING STRESSES AND TOTAL ELONGATION

Ingot Mould Iron No.	Room Temperature		400° C.	
	Ultimate Tensile Stress, tons/sq. in.	Total Elongation, % on 3 in.	Ultimate Tensile Stress, tons/sq. in.	Total Elongation, % on 3 in.
3	10·3	0·80	9·2	0·98
4	6·6	0·60	7·1	1·23
7	5·4	0·55	5·1	1·13
12	8·2	1·00	7·0	1·00
13	6·2	0·80	5·3	0·91
14	5·5	0·82	5·0	0·92

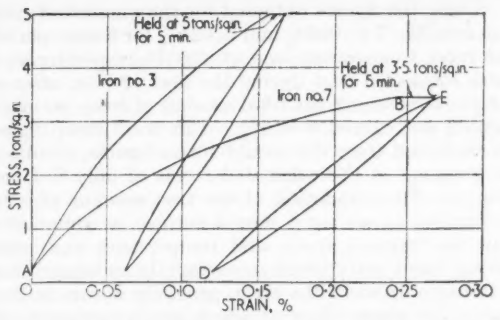


Fig. 10—Loading, unloading, and reloading tensile tests at 400° C.

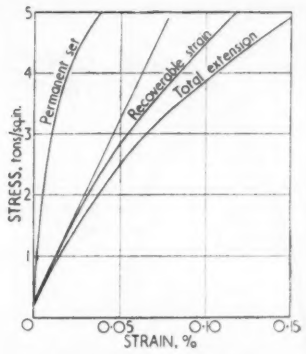


Fig. 11—Set and extension tensile curves obtained on iron No. 3 at 400° C.

high-temperature extensometer as it was more sensitive than that used for the total extension tests. Strains of 7×10^{-6} in./in. could be measured but it was found that the creep taking place at even quite small stresses made such accuracy of reading impracticable. Each of the four irons was loaded to a nominal stress of about 50–60% of the ultimate tensile strength ; this maximum was chosen to ensure that the test piece did not break with the extensometer attached.

Because considerable creep was taking place at the higher stresses, each maximum load was maintained for five minutes in order to measure the amount of creep. The complete stress cycles for irons Nos. 3 and 7 are shown in Fig. 10. As the test piece was unloaded from the maximum load *CD*, a permanent set *AD* remained, and the strain from *C* to *D* represented the recoverable strain. Upon reloading, the stress/strain curve *DE* differed appreciably from the original loading curve *AB*, the point *E* at maximum load lying slightly to the right of *C*. Whereas in the original loading of iron No. 7 a stress of 3·5 tons/sq. in. produced a strain of 0·24%, upon second loading the strain from zero load to 3·5 tons/sq. in. was only 0·15%. Expressed in another way, the stress upon the first loading causing a 0·15% strain was 2·8 tons/sq. in., but the same strain during the second loading required a stress of 3·5 tons/sq. in. Similar differences occurred with the other irons, both at room temperature and at 400° C. The amount of creep measured is given in Table VI together with other data.

Permanent Set and Elastic Extension

A further test piece of each of the four irons was repeatedly stressed by successively increasing increments of load, each time unloading to determine the permanent set. Extension readings were therefore obtained representing the total extension and permanent set corresponding to each ½ ton of load up to the maximum of the test. The difference between the total extension and permanent set represents the ' recoverable ' strain. The three stress/strain curves obtained on iron No. 3 at 400° C. are illustrated in Fig. 11.

When testing ordinary cast iron the recoverable strain curve is practically straight for about 50% of the ultimate strength, but with the ingot mould irons the plotted curve deviates from a straight line at very low loads (*see* Fig. 11). The slope of the curve, however, roughly indicates the relative rigidity of the material, particularly its rigidity after it has been strained. As it was not always possible to determine the slope of this curve at the initial application of load, tangents were drawn at 1 ton/sq. in. The ' apparent ' modulus of elasticity given in Table VI was calculated from the slope of these tangents. The expression ' apparent ' modulus of elasticity, as for a transverse test, is used because, although the iron after straining behaves approximately as an elastic material, it has already undergone a certain amount of plastic straining and cannot therefore be regarded as elastic in the same sense as a steel. With the exception of iron No. 12 the moduli at 400° C. were

Table VI

RESULTS OF STRESS/STRAIN TESTS

Ingot Mould Iron No.	Maximum Stress of Test, tons/sq. in.	Ultimate Tensile Stress, tons/sq. in.		Creep During 5 min. at Maximum Load, %		Apparent Modulus of Elasticity, 10^6 lb./sq. in. (calculated from slope of recoverable strain curve at 1 ton/sq. in.)	
		Room Temp.	400° C.	Room Temp.	400° C.	Room Temp.	400° C.
3	5	11·2	9·4	0·0020	0·0114	14·7	13·3
4	4·5	7·1	7·2	0·0035	0·0132	11·9	10·1
7	3·5	5·3	5·8	0·0054	0·0240	7·5	6·8
12	3·5	6·2	6·9	0·0015	0·0182	12·9	8·3

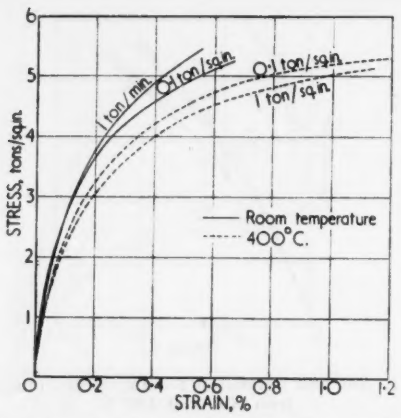


Fig. 12—Effect of rate of loading on tensile stress/strain curves for iron No. 7

about 10% lower than at room temperature and, as in the original transverse tests on the square bars, the moduli generally increased with tensile strength.

After unloading the test piece from the maximum load to 0·2 ton at the completion of the test, it was noticed that a slight recovery occurred while holding it at that low load. On iron No. 7 at 400° C. there was a recovery of 0·002% in 5 min.—only a small amount, but nearly 10% of the positive creep at 3·5 tons/sq. in., which took place during the same time.

Effect of Rate of Loading

During the previous tests a nominal rate of loading of 1 ton/sq. in./min. was chosen, and creep took place, particularly at 400° C., at stresses as low as 2·5 tons/sq. in. With a slower rate of loading the iron would be at the higher stresses for longer periods of time and would afford a greater opportunity for creep to take place, and the extensions corresponding to each stress would therefore be greater. A few tests were therefore carried out to determine the effect of rate of loading on the stress/strain curve.

The results of tensile stress/strain-to-rupture tests carried out on iron No. 7 at room temperature and at 400° C. at loading rates of 0·1 and 1 ton/sq. in./min. are given in Table VII and in Fig. 12. Although the curve for the slow rate of loading lay to the right of the faster loading curve at room temperature, the reverse was true at 400° C. In each case, the greatest elongation was obtained with the lower rate of loading.

CREEP AND GROWTH TESTS

Reference has already been made to creep that takes place at both room temperature and at 400° C. at stresses equivalent to about 50–60% of their ultimate tensile strengths. The amount of creep measured during 5 min. at a nominal load for each of four irons is given in Table VI. As it was calculated that the stresses in the surfaces of ingot moulds reach 3 and 4 tons/sq. in. at temperatures up to 400° C., and it was known that the temperature reached 600–700° C. (temperatures at which iron creeps rapidly), it was expected that a proportion of the strain would be due to creep.

Using the figures obtained for the amount of creep on iron No. 7 (0·005% and 0·024% for 5-min. periods at room temperature and at 400° C. respectively), it was estimated that during the first 12 min. after an ingot was teemed, the total amount of creep occurring would not exceed 0·016%. This total creep figure, if deducted from the mould strain figures, results in a lowering of the calculated stress of only 0·1 ton/sq. in. The estimation of the true amount of creep occurring in an ingot mould surface is complicated by the varying stress and temperature and, since creep takes place much more rapidly as temperature increases, most of the creep probably occurs at temperatures above those at which strain measurements have been made in the B.I.S.R.A. tests.

To derive some data about the creep properties of ingot mould iron, two short-duration creep tests were carried out at 3 and 4 tons/sq. in. at 400° C. on iron No. 4. A growth test to determine what proportion of the strain in a creep test, if any, was due to growth, was included.

The same size of tensile test piece was used as in the previous tensile tests, *i.e.*, 1·128 in. dia. and 3 in. gauge length. The temperature was raised to 380° C. in 6 hr. and was adjusted to 400° C. during the next 16 hr. It was then maintained at 400 $\pm \frac{1}{2}$° C. The full load of the test was applied in 2 min., and the stress/strain curves obtained during loading were both very similar to the previous curves (*see* Fig. 9*b*).

Some data derived from the creep curves in Fig. 13 are given below :

	3 tons/sq. in.	4 tons/sq. in.
Strain due to initial application of load, %	0·117	0·22
Total strain after 24 hr., %	0·162	0·348
Creep during 24 hr. expressed as a percentage of initial strain, %	38	58
Total strain after 15 days, %	0·276	0·66
Creep during 15 days expressed as a percentage of initial strain, %	136	200
Creep rate after 15 days, per hr.	$2·2 \times 10^{-6}$	6×10^{-6}

In the growth test the total increase in length after 20 days was 0·003%. This represents an average rate of growth of 6×10^{-8} per hr. The specimens from the creep tests and the growth test were examined microscopically but did not reveal any difference from the original microstructure.

It was estimated from the creep figures given in Table VI that during the first 12 min. the mould surface may creep 0·016%. Assuming that creep starts afresh after each usage, even this amount repeated 100 times, corresponding with 100 lives of the mould, would give a permanent strain of 1·6%,

Table VII

RESULTS OF TENSILE STRESS/STRAIN-TO-RUPTURE TESTS

Temperature of Test	Rate of Loading, tons/sq. in./min.	Ultimate Tensile Stress, tons/sq. in.	Total Strain, % (3-in. gauge length)
Room temperature	0·1	5·2	0·67
,, ,,	1	5·4	0·55
400° C.	0·1	5·3	1·29
,,	1	5·1	1·13

far more than is found in practice. There appears to be some other factor preventing such a rapid deformation caused by creep.

Owing to the differential expansion through the mould wall, caused by the sudden heating of the mould inner surface as it is filled, tensile stresses will be produced in the outer surface and compressive stresses in the inner surface. There will be some parts within the wall where there is no stress at all. During this heating-up period there will be creep in tension and compression. After stripping, the temperature of the inner and outer surfaces will become equal, the outer surface will have been stretched owing to tensile creep and the inner surface compressed by the compressive creep. At 600–700° C., which is the temperature reached, the metal will be unable to maintain anything more than a very small stress, and the whole mould will be almost completely stress-relieved. Provided the entire mould is then at a uniform temperature and cools without setting up any more temperature gradients, all parts of the mould will contract equally and the mould shape will remain the same as after stripping, larger on the outside which has been stretched, and smaller on the inside which has been compressed.

The condition of no temperature gradient does not exist, however, as the B.I.S.R.A. temperature measurements have shown. Although the inner and outer faces reach practically the same temperature soon after stripping there is still perhaps 100° C. difference between the surfaces and the centre of the wall. The centre of the wall will have to contract more to reach the same temperature as the outer or inner surfaces and will therefore put both surfaces in compression, thereby leaving the centre in tension. The most important temperature range during cooling will be between 600° and 400° C., where the iron changes from a condition of plasticity to one of relative rigidity.

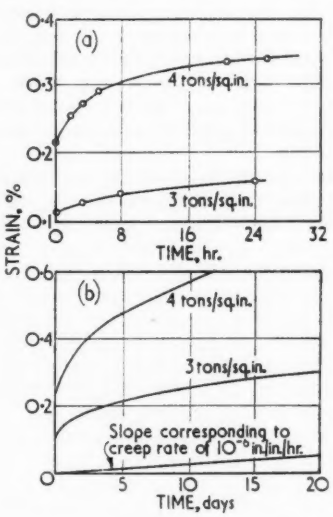


Fig. 13—Creep curves on iron No. 4 at 400° C.: (*a*) For the first 24 hr., (*b*) for 20 days

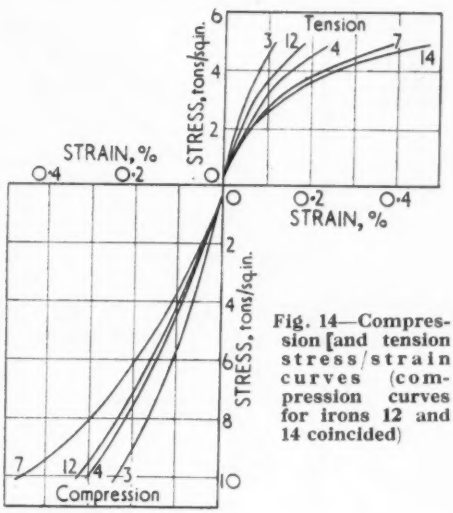


Fig. 14—Compression and tension stress/strain curves (compression curves for irons 12 and 14 coincided)

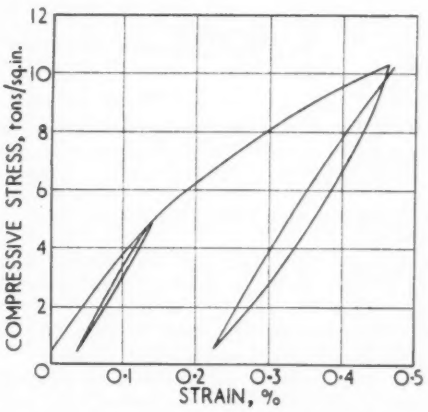


Fig. 15—Compression loading and unloading loops on iron No. 7 at room temperature

The heating and cooling of a mould may, therefore, cause, successively, on the outside surface a tensile strain, tensile creep, compressive creep, and compressive strain, leaving the iron finally under a compressive stress and of dimensions depending upon the relative magnitudes of these mechanical strains. Growth due to structural change and oxide penetration will, of course, have additional effects on dimensions. It has not been possible to devise a method of measuring the strain in the ingot moulds over the complete heating and cooling cycle to verify the nature of any residual strain, owing to the intense heat in the vicinity of the mould walls after a temperature of about 400° C. is reached.

COMPRESSION TESTS AT ROOM TEMPERATURE

Because of the possible existence of compressive stresses in ingot moulds a few compression stress/strain tests were carried out at room temperature. The ultimate compressive stress of cast iron is usually between 3 and 4 times the ultimate tensile stress but

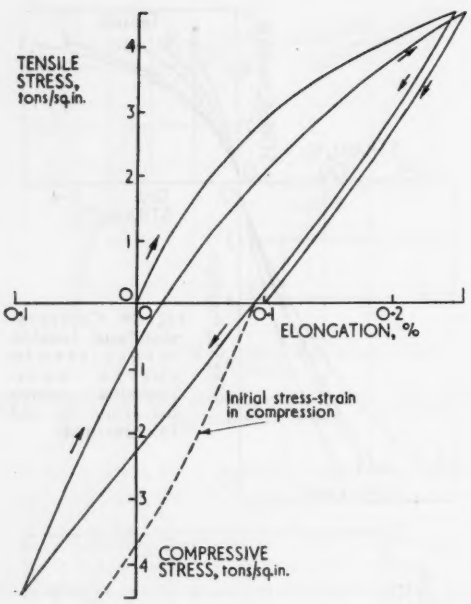


Fig. 16—Effect of reversed tension and compression on iron No. 13

little is known about the stress/strain properties in compression.

Test pieces were machined and ground 4 in. long and 1 in. dia. giving a cross-sectional area of 0·79 sq. in. This was the largest diameter to which a Hounsfield extensometer could be attached and the shortest length that would give clearance for the extensometer between the compression platens of the machine. The compressive strain was measured over a 2-in. length.

Compressive stress/strain curves up to 10 tons/sq. in. were determined at room temperature on irons Nos. 3, 4, 7, 12, and 14. The complete curves are shown in Fig. 14, together with the corresponding tensile curves. One of the test pieces, No. 7, was also unloaded to zero stress from stresses of 5 and 10 tons/sq. in. to determine the unloading and reloading loops (*see* Fig. 15). The results in Fig. 14 show that the straining properties in compression differ appreciably from those in tension, particularly with the weaker irons. The stronger iron No. 3 is strained only a little more in tension than in compression, but the weaker iron No. 14 is strained over four times as much at 5 tons/sq. in.

If the amount of compressive strain in ingot moulds, assuming it exists, were known accurately it is doubtful whether such compressive stress/strain curves as those in Fig. 14 could be used to derive the stress even if they had been obtained over a range of temperature. A cast iron that has previously been strained in one direction, say in torsion or bending, has different stress/strain properties when tested in the reverse direction. Where the stress/strain properties differ in tension and in compression, a curve such as Fig. 16 is obtained. However, the effect of reversed stressing may not necessarily occur like this in a mould since it is expected that the change from tension to compression takes place above 600° C. and the metal will therefore have been stress-relieved before the compression stress occurs.

ENDURANCE TESTS AT ROOM TEMPERATURE AND AT 400° C.

In earlier stress/strain tensile tests the elongation at maximum load was shown to be slightly greater after the second loading than after the initial loading (*see* point *E*, Fig. 10). After repeated applications of load to a test piece of No. 7 iron there was a gradual displacement of the loops to the right (*see* Fig. 17). The total strain had increased by 0·035% during the first 25 cycles and by 0·009% during the next 25, the width of the loops diminishing as the number of cycles increased. There was no appreciable difference, however, in the stress/strain loading curves for the three cycles determined.

Since an ingot mould in service is subjected to many heating and cooling cycles, with consequent application and removal of stress, the effect of repeated stressing on the strain properties of the iron and on the ultimate strength of the iron must be known. The repeated application of a stress of 3·5 tons/sq. in. (65% of ultimate tensile stress) did not materially alter the stress/strain loading curve of iron No. 7 from the 1st complete cycle to the 50th, but there was a gradual increase in the total extension, which might conceivably lead ultimately to failure (*see* Fig. 17).

Endurance tests were carried out on iron No. 4 at room temperature and on both irons 4 and 7 at 400° C. at stresses of 70–93% of their ultimate static tensile strengths. The tests were carried on until fracture, or for 150 cycles, this representing the usual maximum life of a mould. Tensile test pieces of 1·128 in. dia. were repeatedly loaded from 0·2 ton to the maximum load of the test and down again to 0·2 ton, the completed cycle being performed in all but one test at the rate of two per minute. The total extension was measured after each one, five, or ten cycles, according to the stage of the test. The results on irons Nos. 4 and 7 are plotted as percentage strain against number of cycles in Fig. 18.

In the test on iron No. 4 at 400° C. failure occurred after 80 applications at 5·5 tons/sq. in. This was at 77% of the ultimate tensile stress in a static test at

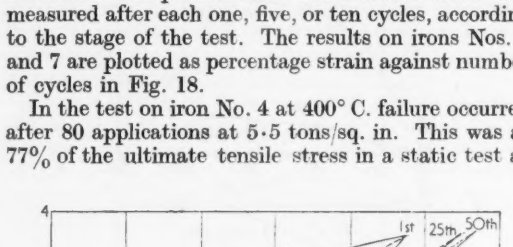
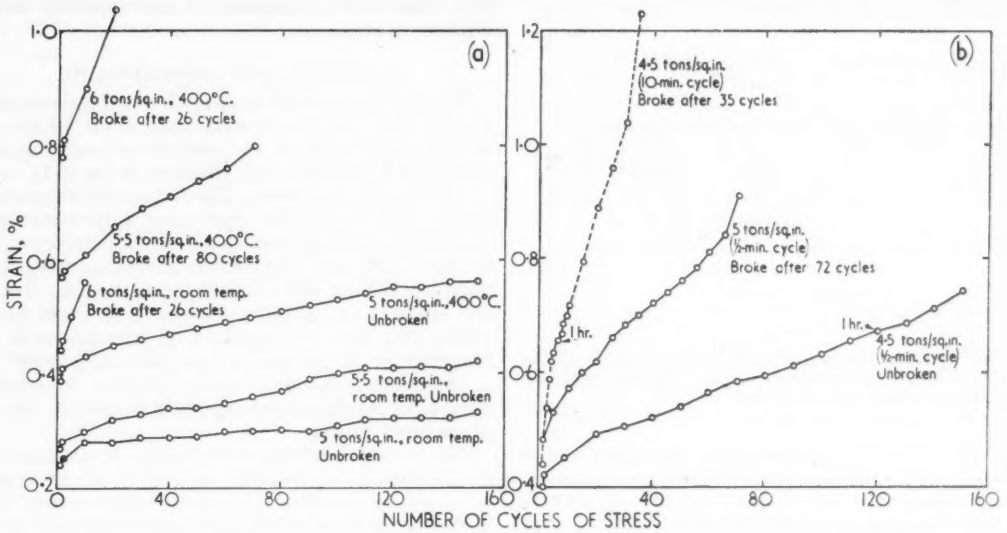


Fig. 17—Effect of repeated application of stress to a tensile bar of iron No. 7 at 400° C.



(*a*) **Iron No. 4 at room temperature and at 400° C. Average U.T.S. at room temperature = 6·8 tons/sq. in., and at 400° C. = 7·1 tons/sq. in.**

(*b*) **Iron No. 7 at 400° C. Average U.T.S. at 400° C. = 5·4 tons/sq. in.**

Fig. 18—Effect of period of cycle on repeated stressing

400° C. Iron No. 7, however, withstood 150 applications at 4·5 tons/sq. in. (83% of the ultimate tensile stress) without failure but with an increase in total extension from 0·40 to 0·74%.

Creep was obviously taking place during the tests and contributing toward ultimate failure. A test with prolonged loading and unloading was therefore carried out on iron No. 7 at 4·5 tons/sq. in., a stress that had not caused failure with the ½-min. cycle even after 150 applications. The stressing cycle consisted of holding the maximum load for 9½ min., and unloading and reloading during the next ½ min., thereby giving a 10-min. cycle. The pronounced effect on the endurance graphs is shown in Fig. 18*b*. Failure occurred after 35 cycles, giving a total strain of 1·23%. The increase in strain after the initial application of load was 0·79%, whereas in the test with a ½-min. cycling period the increase for the same number of cycles was only 0·11%.

Endurance tests under these conditions of stress and temperature are clearly a combination of creep and fatigue. When the rate of loading is slow or the cycle is such that the iron is at a high stress for a long period, creep may have a dominating influence in causing failure, whereas if the stressing cycle is much quicker the creep effect will be less and failure is then more likely to be caused by fatigue.

The failure of an iron by repeated applications of a stress below its static ultimate tensile stress is a factor to be taken into account in considering failure stresses in a mould, but it is hardly to be expected that a figure can be obtained for a limiting fatigue stress from a simple laboratory test, since this should take into account the variable factors (stress, rates of increase of stress, reversal of stress, creep) during the repeated use of an ingot mould.

EFFECT OF SUBSEQUENT HEAT-TREATMENT ON THE STRESS/STRAIN PROPERTIES OF AN ALREADY STRAINED BAR

All the strain measurements made by Buttler and Glaisher (*see* p. 287) were on new moulds, which had not previously been stressed. Stress calculations were accordingly based on the initial loading curve of the tensile stress/strain diagram. During the second application of load, however, the stress/strain characteristics of the tensile bar in all the irons tested were entirely different, since the permanent set had been removed and almost all the applied strain was recoverable. For equal strains, the equivalent stress during the second and subsequent applications of load was much greater than during the first application of load. It appeared that after the first use of the mould the permanent set would have been removed, and the measured strains caused by teeming might be entirely different. The stresses would then be calculated from the stress/strain curve obtained by reloading.

This might be so if the mould temperature did not exceed 400° C. and if the second and subsequent ingots were poured immediately. In practice the outer surface of the mould reaches 600–700° C. before it is stripped and starts to cool. A test was therefore carried out to see how the stress/strain characteristics of the iron change by raising its temperature to 620° C. after testing at 400° C., cooling to room temperature, and then again raising to 400° C. This is the approximate temperature cycle that takes place in an ingot mould during the teeming, stripping, cooling, and teeming of the next ingot.

A tensile bar of ingot mould iron No. 13 was heated to 400° C. and a stress/strain loading, unloading, and reloading test was carried out (*see* curve *ABCD*, Fig. 19). The bar was then heated to 620° C., immediately

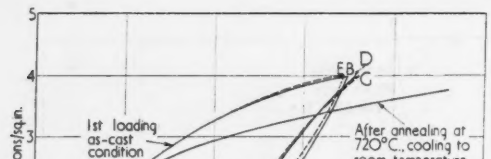


Fig. 19—Effect of stress-relieving and annealing on the stress/strain properties of an already strained test bar of iron No. 13, at 400° C.

cooled slowly to room temperature, and again heated to 400° C., and a further complete loading, unloading, and reloading test was carried out (curve *AEFG*). The initial loading curve after heating to 620° C., *AE*, was almost coincident with the initial curve *AB*, obtained before the test piece had been strained. The difference in the slope of the unloading and reloading loop may be because partial spheroidization has taken place and has changed the straining properties, although this would be expected to affect also the initial loading curve.

The action of heating to 620° C., cooling to room temperature, and reheating to 400° C. (or part of this cycle) apparently restores the iron to a condition that has almost the same stress/strain properties as the original as-cast material. An ingot mould subjected to the same temperature cycle during teeming and stripping would also be expected to possess the same stress/strain properties in the second cast as in the original, and therefore the same initial loading curve could be used to convert strain to stress.

The same tensile bar was then heated to 720° C. and held for 10 hr., cooled slowly to room temperature, and again reheated to 400° C. The purpose of this heat-treatment was to spheroidize and at least partially decompose the pearlite, a condition which ingot moulds would reach if they were repeatedly brought into the 600–700° C. temperature range during use. A stress/strain test to fracture was carried out at 400° C. (Fig. 19). The ultimate tensile stress was 3·8 tons/sq. in. and total elongation 0·46%, both figures being very much lower than the 5·3 tons/sq. in. and 0·91% which were obtained on the as-cast test piece tested at 400° C. The low strength would be expected from the annealing but an annealed unstressed iron would also be expected to have a greater elongation than the as-cast material. The low elongation obtained in this test was evidently due to a damaging effect caused by the bar having already been stretched. In each of the previous tests on this same bar there had been permanent sets of 0·17%.

This drop in strength and ductility has an important bearing on the behaviour of ingot moulds, since the permanent set at each heat would be cumulative and might consequently reduce the amount of strain that the mould iron is capable of withstanding before fracture occurs.

SUMMARY AND CONCLUSIONS

The main purpose of these mechanical tests on ingot mould iron was to provide data from which the mechanical strains on the surfaces of ingot moulds, measured by Buttler and Glaisher (*see* p. 287), could be converted to stresses. The tests have shown that ingot mould irons differ appreciably in their strengths and stress/strain properties at all temperatures. By interpolation, the stress/strain curves at room temperature and at 400° C. have been used by Buttler and Glaisher to calculate stresses in an ingot mould during the first few minutes of teeming until the temperature of the mould face has reached 400° C.

The mechanical tests were extended to cover a number of conditions which might be met in the life of an ingot mould.

The practical difficulties of making strain measurements during the complete period of the heating of an ingot mould during teeming and cooling after stripping, have prevented a complete analysis of the behaviour of the mould being made. The tensile stress on the outer surface reaches a maximum after about 4 min. and is maintained at least until the temperature reaches 400° C. Creep can take place at all temperatures but the rate increases with temperature, particularly above 400° C. During teeming it is supposed that, at the same time as the outer surface develops a tensile stress, the inner surface is put into compression. As both these surfaces, and the wall between them, eventually reach temperatures of 600–700° C., all parts of the mould will be subjected to direct tension or compression and a corresponding tensile or compressive creep. On cooling, the stresses may be in tension or compression, depending upon the temperature gradient throughout the wall, and these will cause further creep.

Further tests have shown that a number of factors govern the behaviour of a mould during the second and subsequent usage. An ingot mould iron after the first application of a load, as with other cast irons, behaves differently upon the second loading. However, before a mould itself is re-stressed during the teeming of the second ingot it has been raised to a temperature of 600–700° C., the temperature at which stress-relief is very rapid. Because of uneven cooling, however, it may be in a state of residual tensile or compressive stress by the time it has fully cooled after the first cast. In compression, most of the irons were more rigid than in tension, *i.e.*, they deformed less for a given stress, particularly at the higher stresses. Furthermore, the stress/strain properties in tension are known to be affected by the iron having been previously stressed in compression.

Of major importance was the response of the irons to treatment in the 600–700° C. range. After heating to 620° C. and cooling to room temperature an iron that had already been stressed at 400° C., the original stress/strain properties at 400° C. were restored, but on subsequent annealing at 720° C. for 10 hr. and reducing to 400° C., the ultimate tensile strength and total elongation had dropped appreciably. This is attributed to both spheroidization and decomposition

of the pearlite, and to an apparent damaging effect caused by the test piece having twice previously been stressed close to the ultimate.

To take into account the repeated use of a mould, some endurance tests were carried out whereby a tensile bar was repeatedly loaded at ½-min. intervals at stresses of 70–90% of the ultimate tensile stress. On one of the irons failure occurred after 80 applications at 77% of the ultimate tensile stress. These tests show that failure of a mould can be expected at stresses lower than the ultimate tensile stress, as measured in a laboratory short-time test, but they do not take into account the effect of any possible reversal of stress, which it is believed may take place, nor the effect of rate of loading. In an endurance test in which the load was maintained for 9½ min. between each removal and re-application of stress, considerable creep took place and failure occurred after a relatively small number of applications and with a large plastic strain.

The factors that need to be taken into account in considering the failure of a mould by cracking include the effect of creep on the properties of the iron, the possible existence of residual tension or compression in the mould, stress-relieving at the higher temperatures, the apparent recovery of the stress/strain properties and lowering of ductility caused by stress-relieving after straining, the change in structure, and the growth and oxidation of the iron.

Acknowledgments

The author is indebted to the Council and Director of the British Cast Iron Research Association, in whose laboratories the work was carried out, for permission to publish this paper, and also to Mr. K. B. Palmer for his assistance in carrying out the mechanical tests.

POISSON'S RATIO FOR CAST IRON USED FOR INGOT MOULDS

By J. Woolman, M.Sc.

SYNOPSIS

A lateral extensometer suitable for attaching to a test piece in a cylindrical electrical furnace has been designed and constructed. With this, in conjunction with a conventional type Lamb roller extensometer, Poisson's ratio determinations have been made on a number of ingot mould irons, both at room and elevated temperatures. The value of the Poisson's ratio is shown to vary with the stress, the temperature, and with repeated applications of the load, although with the latter the ratio tends to a constant value.

A theory is put forward to account for the observed variation in the properties of the iron with graphite size. This postulates that some separation of the metal from the graphite flakes occurs when the irons are subjected to tensile stresses.

Because of the variations in the observed values of Poisson's ratio it is difficult to suggest an appropriate value for use in calculations unless some knowledge of the tensile properties of the irons is available.

Introduction

In all calculations of stresses induced in ingot moulds, either based on the temperature distribution throughout the mould or on the measured dilatations at various positions of the mould, one of the factors involved is Poisson's ratio (ρ). The factor usually occurs in the form of $(1 - \rho)$ in the denominator of the expression concerned and it is important, therefore, to have some knowledge of its value so that the estimate of the stresses shall be as accurate as possible.

Little reliable data exist for Poisson's ratio of cast iron at room temperature and no reference has been found to any determination at elevated temperatures. Values between 0·23 and 0·31 are quoted[5] for Poisson's ratio of cast iron. Some tests carried out by the author in April, 1942,* on two samples of ingot mould iron using a lateral extensometer, previously used for the determination of Poisson's ratio of steels, showed that the values of Poisson's ratio varied with the load as follows :

Stress, tons/sq. in.	Poisson's Ratio Sample *D*1	Sample *D*2
0–0·5	0·17	0·03
0–1·0	0·13	0·03
0–1·5	0·09	0·04
0–2·0	0·07	0·07

With the same extensometer a test on Armco iron gave 0·28. Both the samples appeared to be porous, particularly sample *D*2, and they were weak and broke at a stress slightly in excess of 2 tons/sq. in.

The lateral extensometer previously used was unsuitable for tests at elevated temperatures, because the complete assembly could not be inserted in a

* The results have not been published.

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Mr. Woolman, Chairman of the Stresses in Moulds Group, is at the Brown-Firth Research Laboratories.

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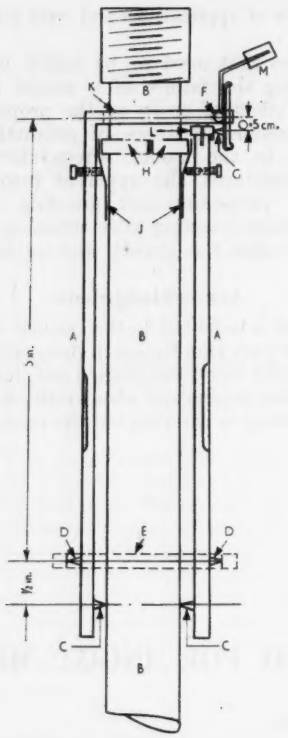

Fig. 20—Diagram of lateral extensometer

suitable furnace. To design a lateral extensometer which, with a longitudinal extensometer, could be mounted on a test piece and the whole inserted in a small cylindrical furnace, was considered the only method of obtaining the desired results, since all other methods of determining Poisson's ratio depended on the assumption that the material behaved elastically, and it is known that cast iron does not.

The longitudinal extensometer presented no difficulties because extensometers of the Lamb roller type are in constant use for creep tests and could easily be modified to suit any necessary changes in design of the test piece. The longitudinal extensometer was made to operate on a 3-in. gauge length. The lateral extensometer, on the other hand, had to be applied to the test piece near the middle of the gauge length clear of the longitudinal extensometer, and since it worked on a relatively small initial diameter of test piece, a sufficiently high magnification was necessary to enable reasonably reliable estimations of the contraction to be determined.

To permit a cylindrical furnace to surround the whole assembly it was necessary that the two extensometers mounted on the test piece should not occupy a too great volume. The bore of this furnace was to be as small as possible and so designed that the temperature of the test piece was uniform over the gauge length.

The test piece used had a 0·798-in. dia. (equivalent to $\frac{1}{2}$ sq. in. in area) and its parallel portion extended beyond both ends of the furnace, coupling it with suitable adapters to the cross-heads of the tensile-testing machine. The overall length of the specimen was governed by the available space between the cross-heads of the machine and was fixed at 10 in. between adapters. Beyond this length of parallel portion, the test piece widened to 1 in. dia., and was threaded with Whitworth threads to fit into the adapters.

Design of the Lateral Extensometer

After various initial trials, a suitable extensometer was developed for lateral measurements ; this is shown diagrammatically in Fig. 20. It consists of two rigid lever arms *A*, designed to operate on either side of the test piece *B* and diametrically opposite each other. The two arms *A* were recessed at a position about the middle of their length to permit the longitudinal extensometer to be fitted into position. At the bottom end and on the inner side of each lever arm a knife edge *C* was fixed, which rode on the test piece. Half an inch above this knife edge and on the opposite side of each lever arm was a similar knife edge *D* designed to ride in a stirrup *E*, which was grooved at each inner side to take the knife edge. This stirrup acted as a fulcrum and, by means of the two lever arms rotating about the knife edges *D* at the stirrup, a primary magnification of 10 : 1 was effected at a point outside the top of the furnace. The magnification was further increased by incorporating a 400 : 1 optical lever device in the form of a mirror on horizontal pivots *F*, mounted one on each leg of a horizontal **U**-piece *K*, which surrounded the test piece without touching it, at the top of one lever arm. At a position 5 mm. below the line of the pivots, a knife edge *G* was mounted on the mirror casing and this knife engaged with an adjustable hardened steel anvil *L*, fitted to the top of the second lever arm, which enabled the test to be started with the mirror approximately vertical. The very small angular movement of the mirror as the test piece contracted was measured by a suitable telescope and scale. The two lever arms of the lateral extensometer were held in position on the test piece by two curved horizontal leaf springs *H* fixed to the lever arms above the furnace, and pressure was thus applied outwards from the test piece in the same direction as the expected movement. This assisted the arms to rotate about the fulcrum, and caused the two lower knife edges to fit firmly against the test piece at each end of a diameter within the gauge length. Two small vertical leaf springs *J* were added as a stabilizing device.

The furnace, which enclosed the necessary portion of the assembled test rig, was 8½ in. long by 3 in. internal diameter, and was suitably wound with 80/20 nichrome wire to give a uniformly heated 3-in. gauge length in the specimen.

Characteristics of the two extensometers were as follows :

Extensometer	Gauge Length Between Knife Edges	Strain Measurements
Lateral	0·798 in. (dia.)	1 cm. on scale = 0·0000627 in./in.
Longitudinal	3 in.	1 cm. on scale = 0·00003333 in./in.

The apparatus was first used for testing a 0·30% carbon steel in the normalized condition. Several determinations of Poisson's ratio for this steel, in the elastic range, were obtained before, and at intervals during, the testing of the cast-iron samples at room temperature. Values ranged from 0·255 to 0·283, and the average of eight determinations was 0·267.

Many determinations of Poisson's ratio at room temperature have been made on steels, using longitudinal and transverse extensometers : Johnson and Opila[6] give 0·284–0·308, averaging 0·297 ; Lyse and Godfrey[7] give 0·271–0·302 ; Bauschinger[8] quotes 0·27–0·30 for iron and steel ; and Morrow[9] gives 0·27–0·28 for mild steel. From Coker's determination[10] of the longitudinal and lateral strains for a sample of mild steel, the deduced value of Poisson's ratio is 0·262.

The author, using the room-temperature lateral extensometer mentioned above, obtained a value of 0·267 for mild steel. This indicates that the present extensometer gives reliable results accurate at least to $\pm$ 0·01 provided that the determinations are made with a load increment of about 10 tons/sq. in. With the load increments used for cast iron the possible error must necessarily be greater than this figure, in inverse proportion to the load increment used for the tests.

DETERMINATION OF POISSON'S RATIO

Materials

Four 2-in. sq. bars of cast iron cut from 6 in. × 4 in. section material were supplied by the British Cast Iron Research Association. The material had been examined for tensile and other properties for the Stresses in Moulds Group. Details of the four samples, taken from the Group's report, are :

B.C.I.R.A. No.	Description	Total Carbon, %	Si, %	Mn, %	S, %	P, %
3	Standard + 25% secondary hematite	3·52	1·32	0·61	0·082	0·066
4	Raised phosphorus (0·25%)	3·84	1·61	0·66	0·065	0·21
12	Standard material	3·82	1·49	0·43	0·086	0·076
14	Standard material	4·12	2·07	1·03	0·051	0·036

Experimental Procedure

From each sample it was possible to make only a single test piece, which had to suffice for all the tests carried out at both room and elevated temperatures. The load during each test was, therefore, limited to a maximum value corresponding to 4 tons/sq. in., except in the tests on iron No. 3 at 450° C., to ensure that the specimen did not break before all the tests were completed. Readings were taken at each 0·5 ton/sq. in. increment of load both on loading and unloading. This procedure was repeated for two or more similar cycles.

The procedure for tests at elevated temperatures was similar. The test piece was heated to the desired temperature and soaked for 1 hr. under no load. Three thermocouples were attached to the specimens, one at the top end of the gauge length, one at the bottom, and the third opposite the knife edges of the lateral extensometer. The maximum difference between the three thermocouples occurred when the tests were carried out at 650° C., when the difference between top and bottom thermocouple readings was 20° C. At 450° C. the three couples agreed to within 2° C. For the tests at 650° C. the middle thermocouple was arranged to read this temperature.

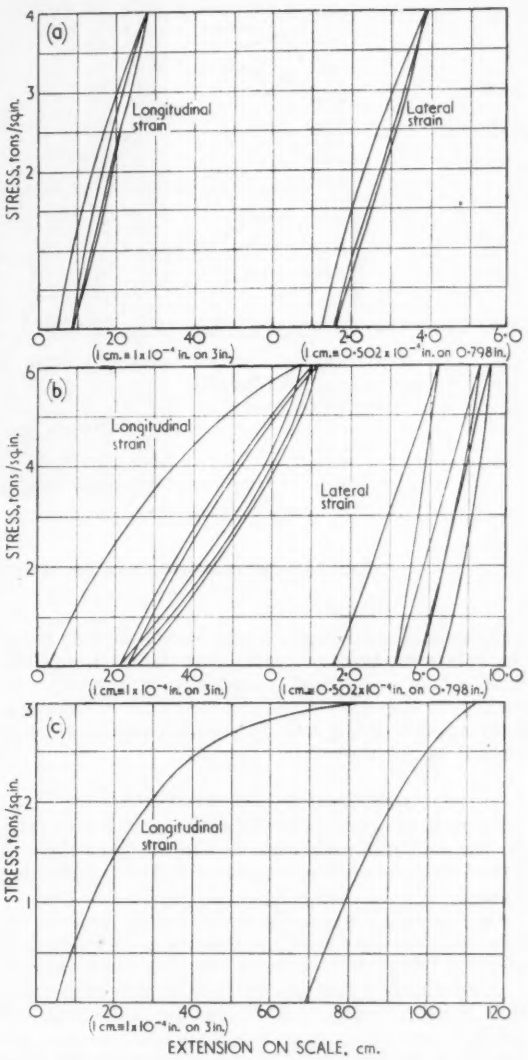
(a)
Longitudinal strain
Lateral strain
STRESS, tons/sq.in.
(1 cm. = 1 x 10⁻⁴ in. on 3 in.)
(1 cm. = 0·502 x 10⁻⁴ in. on 0·798 in.)
(b)
Longitudinal strain
Lateral strain
STRESS, tons/sq.in.
(1 cm. = 1 x 10⁻⁴ in. on 3 in.)
(1 cm. = 0·502 x 10⁻⁴ in. on 0·798 in.)
(c)
Longitudinal strain
STRESS, tons/sq.in.
(1 cm. = 1 x 10⁻⁴ in. on 3 in.)
EXTENSION ON SCALE, cm.

Fig. 21—Stress/strain diagram for iron No. 3: (*a*) At room temperature, (*b*) at 450° C., (*c*) at 650° C.

The heating current for the furnace was supplied from a constant voltage alternator with thyratron control gear, and the temperature of the test piece remained constant to within 1° C. whilst the test was being carried out.

Results

Typical stress/strain curves given in Fig. 21 were obtained at room and elevated temperatures on iron No. 3. Figures 21*a* and *b* show the effect of repeated

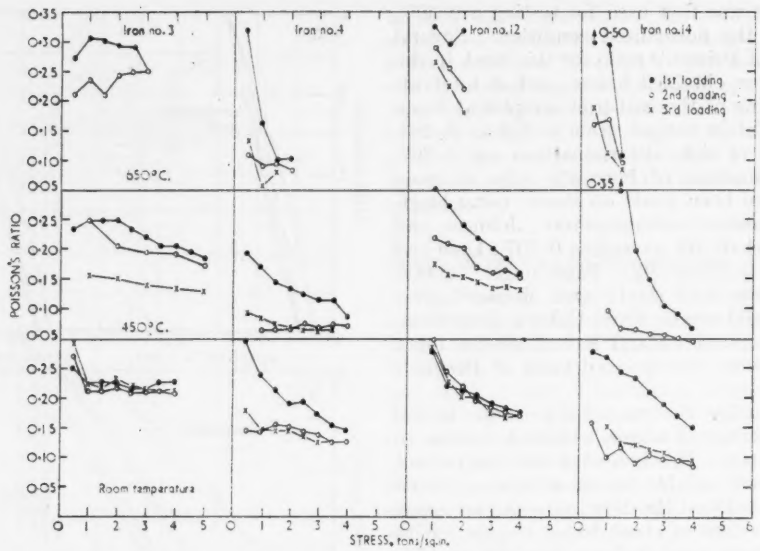

Fig. 22—Stress/Poisson's ratio curves for the four irons at various temperatures

loadings and unloadings. From curves such as these the values for Poisson's ratio were deduced, and the final results are shown graphically in Fig. 22. In each case Poisson's ratio was determined from the total strain resulting from the applied stress, which is plotted as the abscissa.

DISCUSSION OF RESULTS

There is an appreciable difference in Poisson's ratio for the four different irons, but in all cases there is a marked tendency for this ratio to fall with increasing stress.

On repeated loadings the ratio tends to settle down to a constant curve. This tendency is more marked at room temperature than at elevated temperatures.

A relationship appears to exist between the value that Poisson's ratio tends to assume under repeated loadings with the highest stress applications, and the tensile characteristics of the irons. Table VIII gives the tensile strength of the irons, Young's Modulus (deduced from the mean slope to 3 tons/sq. in. of the author's stress/longitudinal strain curves), total percentage deformation at 4 tons/sq. in., and the approximate Poisson's ratio, which the iron tends to have on repeated loading. The irons have been arranged in decreasing order of Young's Modulus and the same order is followed by the values for tensile strength and Poisson's ratio at both room and elevated temperatures, whilst the values for the total deformation at 4 tons/sq. in. are in the reverse order. The stability of Poisson's ratio with increasing values of stress, and the consistency on repeated loading, are in the same order. Microstructures of the irons were examined to ascertain whether they contained any features that might explain these facts.

The surface finishes of the test pieces were appreciably different, as shown in Fig. 23. Specimen No. 3 had a smooth surface and the others showed what at first appeared to be increasing amounts of porosity, in the order of decreasing values of Poisson's ratio. Microexamination showed, however, that none of the samples was actually porous, but that the surface appearance was associated with the coarseness of the graphite, as illustrated in Fig. 24, which shows unetched sections in each case cut from a position in the test piece adjacent to the point where the lateral extensometer was attached. Irons Nos. 3 and 12, especially the former, have a much finer graphite

Table VIII

MECHANICAL PROPERTIES OF CAST IRON AT VARIOUS TEMPERATURES

	Room Temperature				450° C.	650° C.
Iron No.	Young's Modulus, lb./sq. in. × 10^6	Tensile Strength, tons/sq. in.	Total Deformation at 4 tons/sq. in., %	Poisson's Ratio	Poisson's Ratio	Poisson's Ratio
3	13·1	10·3	0·076	0·21	0·14	0·25
12	10·5	7·7	0·100	0·175	0·14	0·18
4	6·95	7·7	0·158	0·125	0·07	0·08
14	5·2	5·7	0·248	0·10	0·05	0·09

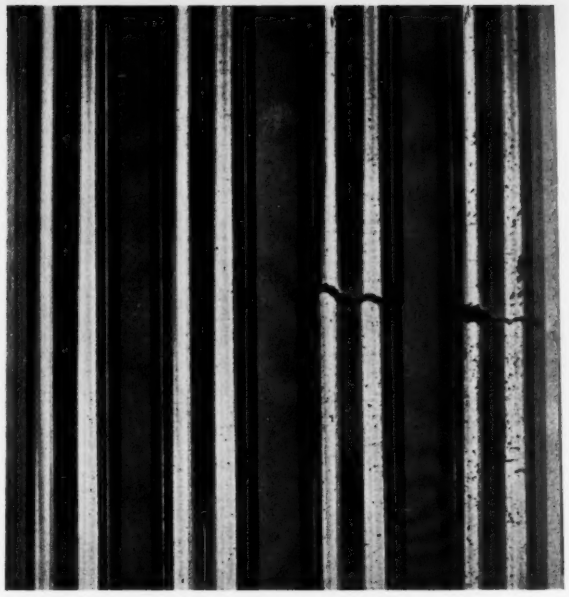

Fig. 23—Surface finish of the test pieces

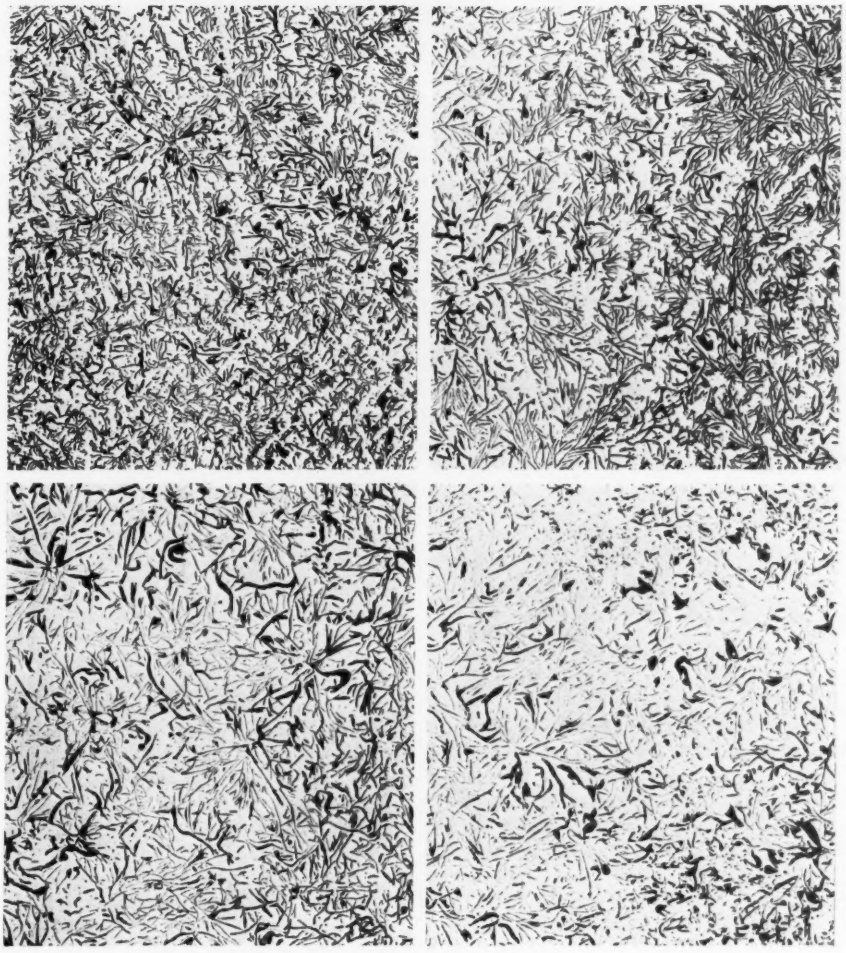

Fig. 24—Microstructure of unetched sections of the four irons × 10

[*Woolman*
[*To face p.* 276

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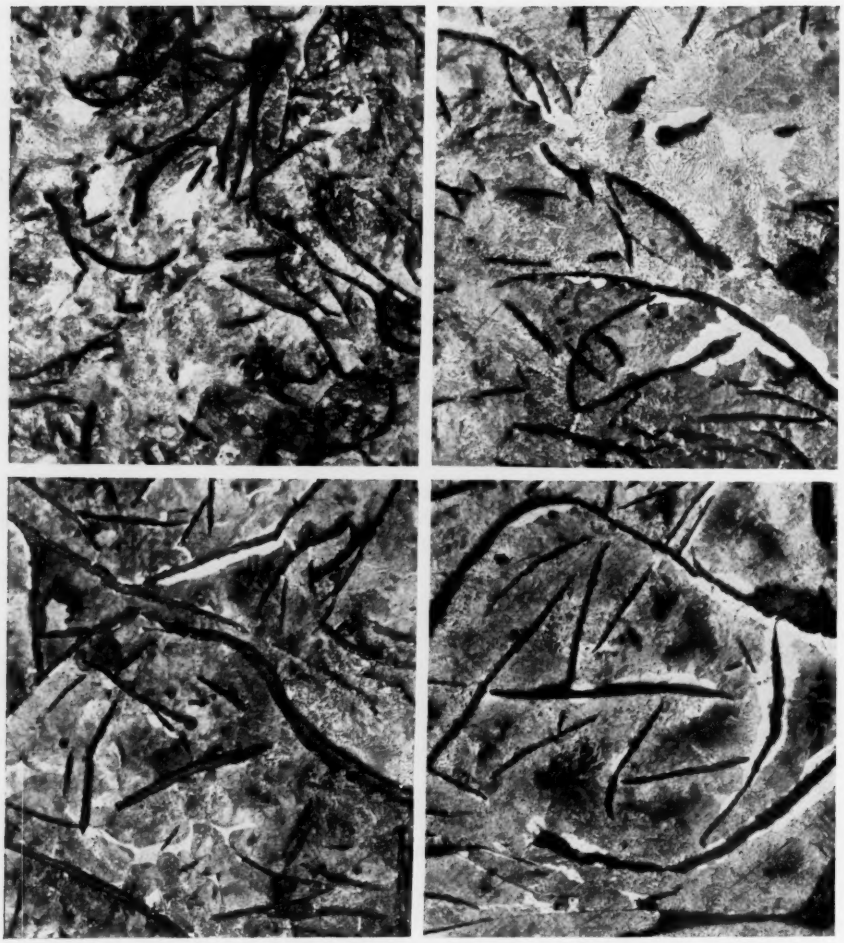

No. 3

No. 12

No. 4

No. 14

Fig. 25—Microstructure of etched sections of the four irons × 100

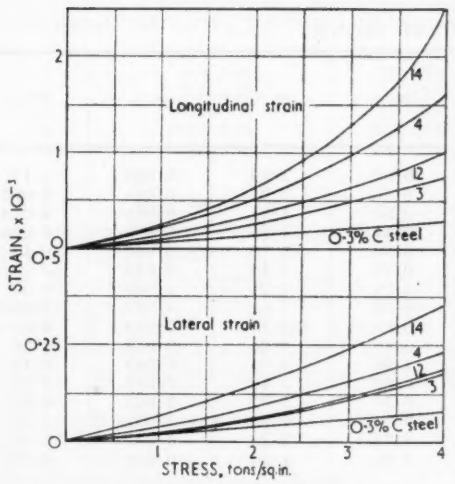

Fig. 26—Initial stress/longitudinal strain and stress/lateral strain curves for the four irons and for mild steel

formation than irons Nos. 4 and 14, in which the graphite is very coarse. At a higher magnification (Fig. 25), the etched structures of these four irons also show a difference in the amount of ferrite present. Iron No. 3 is practically free from ferrite and there is most in iron No. 14, whilst irons No. 12 and No. 4 are intermediate in the amount of ferrite present, there being perhaps a little more in iron No. 12 than in iron No. 4.

A possible explanation of the variation in the properties of the four irons is that in tension the metal part of the structure tends to separate from the graphite flakes to an extent which depends on the fineness of the graphite formation. This would explain not only the surface appearance of the tensile test pieces after machining, but also the greater rate of extension of the coarser graphite irons under load, *i.e.*, the lower Young's Modulus of these irons. Also, on account of the notch effect at the ends of the flake, one would expect weaker irons with the coarser flakes. Further, if one imagines what happens in tension to a test piece containing a number of transverse disc-shaped cavities, one would expect relatively smaller differences in the transverse contraction with different sizes of cavity than those obtained in the longitudinal extension. Thus the pieces with large cavities would be expected to have a lower Poisson's ratio than those with smaller cavities. The initial stress/longitudinal strain and stress/lateral strain for the four irons together with those for mild steel are plotted in Fig. 26. The difference between the lateral strains of the irons and that of the steel is proportionally much less than the difference between the longitudinal strains of the two types of material.

Acknowledgments

The author thanks Dr. C. Sykes, F.R.S., Director of Research, Brown-Firth Research Laboratories, for permission to publish this paper, and his colleague, Mr. N. B. McGregor, for carrying out the experimental work.

GROWTH CHARACTERISTICS OF SOME CAST IRONS USED FOR INGOT MOULDS

By W. C. Heselwood, B.Sc., A.Met., F.I.M., and F. B. Pickering, A.Met., L.I.M.

SYNOPSIS

The work described originated in an attempt to devise a simple test which would assess the susceptibility to growth of different ingot-mould irons. Repeated heating and cooling tests were followed by determinations of the isothermal growth at different temperatures, and the measurement of growth occurring during 5 hr. at 700° C. under conditions of limited access of air (to minimize scaling) was finally adopted as an arbitrary test, and was applied to 16 irons of differing analyses.

From the results, a tentative relationship has been obtained indicating the influence of Si, Mn, and P on susceptibility to growth. The mechanism of growth in cast irons is discussed, and a suggested mechanism is tested experimentally. Correlation of the test results with the lives of related ingot moulds is largely masked by other variables, but the possibility of a relationship is briefly discussed in an Appendix.

Introduction

THIS investigation was undertaken to assess the growth characteristics of cast irons used for the manufacture of ingot moulds. The problem of determining which are the important factors affecting the life of an ingot mould is complex, and is being studied by many workers. It seemed reasonable to assume, however, that the degree to which an ingot mould grows in service may be one relevant factor, and the purpose of the present work was to provide

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Mr. Heselwood and Mr. Pickering are in the Research and Development Department of The United Steel Companies, Ltd.

Table IX
ANALYSES OF THE CAST IRONS

Iron No.	Cast No.	Carbon, %			Mn, %	Si, %	S, %	P, %
		Total	Combined	Graphite				
1	12/11	3·31	0·34	2·97	0·85	2·54	0·060	0·17
2	30/9	3·31	0·62	2·69	0·70	2·01	0·056	0·085
3	6/8	3·50	0·68	2·82	0·59	1·91	0·086	0·074
4	7/10	3·59	0·67	2·92	0·81	1·36	0·050	0·066
5	18/7	3·69	0·66	3·03	0·88	1·16	0·040	0·19
6	11/7	3·76	0·68	3·08	0·90	1·18	0·043	0·20
7	3/7	3·79	0·87	2·92	1·25	1·24	0·040	0·20
8	2/9	3·50	0·76	2·74	0·88	1·61	0·057	0·063
9	16/9	3·33	0·40	2·93	0·83	2·12	0·040	0·17
10	23/7	3·35	0·71	2·64	0·86	1·26	0·044	0·18
11	8/7	3·62	0·64	2·98	1·06	0·96	0·043	0·19
12	1/7	3·52	0·38	3·14	0·80	1·46	0·051	0·15
13	31/7	3·55	0·73	2·82	0·58	1·07	0·083	0·125
14	12/9	3·69	0·73	2·96	0·63	1·03	0·061	0·055
15	21/7	3·67	0·76	2·91	0·75	1·23	0·042	0·21
16	24/7	3·65	0·50	3·15	0·86	1·26	0·048	0·155

some basic information on the growth characteristics of a range of ingot-mould irons.

The Second Report of the Ingot Moulds Sub-Committee[11] gives 845° C. as the maximum recorded temperature of ingot moulds in use, and a figure of 850° C. has therefore been adopted as a maximum for the present tests.

The influence of different thermal treatments (both at varying temperatures and isothermal) on the degree of growth was first examined using a few selected irons and, from the evidence so obtained, an endeavour was made to devise a simple test which would quickly assess the general susceptibility of any given iron to growth. This test was then applied to the remaining irons of the series. From data so obtained, an assessment has been made of the effect of composition (particularly Mn, Si, and P) upon susceptibility to growth. The mechanism of growth in cast iron has been discussed. The possibility of a correlation between mould life and susceptibility to growth is briefly dealt with in an Appendix.

EXPERIMENTAL PROCEDURE

Materials

A series of 16 irons was selected from a number of samples, each 20 in. long × 6 in. dia., and all of different analysis, which had been cast in the foundry of Messrs. Steel, Peech and Tozer. The analyses of the 16 irons are shown in Table IX.

Five of these materials (iron Nos. 1, 2, 3, 4, and 5) were selected as representing a useful range of analyses for the preliminary work to establish a simplified test method.

Test Methods

The dilatometer work was carried out in a dilatometer constructed in the authors' laboratory, which employed 2 in. × $\frac{7}{16}$-in. dia. test pieces drilled to a depth of 1 in. to accommodate a thermocouple. The early work developed by stages, and it was found that when further specimens of a particular iron were required, material was not always available from a similar position in the test block, and it is believed that this largely accounts for some variability in the observed growth in certain tests, which are partly comparable (*e.g.*, the first 10 cycles in Fig. 28 for

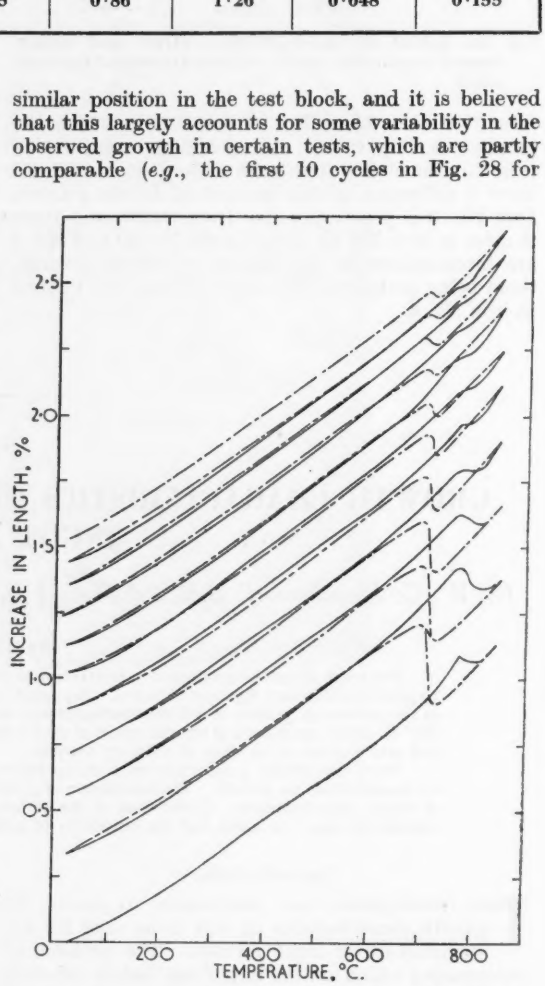


Fig. 27—Length changes in iron No. 2 during ten cycles of heating and cooling, 20° → 850° → 20° C., in 'vacuum'

Table X

THERMAL CRITICAL RANGES OF IRONS

Iron No.	Heating, °C.	Cooling, °C.
1	795–845	755–700
2	775–820	745–695
3	755–770	710–690
4	750–770	705–680
5	760–780	710–670

iron No. 2). In later work, care was taken to retain enough material from the mid-length, mid-radial position for further tests if required.

The dilatometer equipment was evacuated by a single-stage rotary pump, which maintained a ' vacuum ' of approx. 0·1–0·5 mm. of mercury. This can be considered only as a condition of limited access of air, and was adopted to avoid gross scaling of the specimen.

Some supplementary micro-examination was also made.

TEST IN ' VACUUM '

Heating and Cooling Tests

Ten Cycles, 20° → 850° → 20° C., in ' Vacuum '— A specimen of each of five selected irons was heated and cooled 10 times through the cycle 20° → 850° → 20° C. in ' vacuum.' The average rate of heating and cooling above 600° C. in these and in all other cyclic tests was about 5° C./min.

A typical family of curves so obtained is shown in Fig. 27, and the growth results from this and the

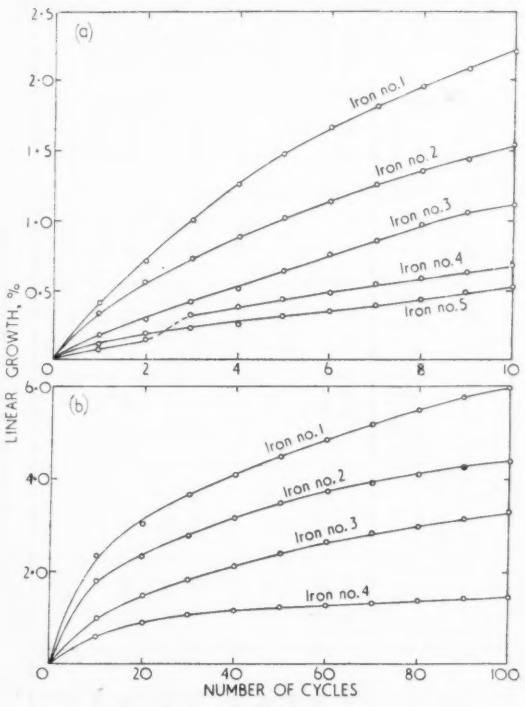


Fig. 28—Curves showing the growth of cast irons during repetitive cyclic heating in ' vacuum ': (*a*) 20° → 850° → 20° C., (*b*) 600° → 850° → 600° C.

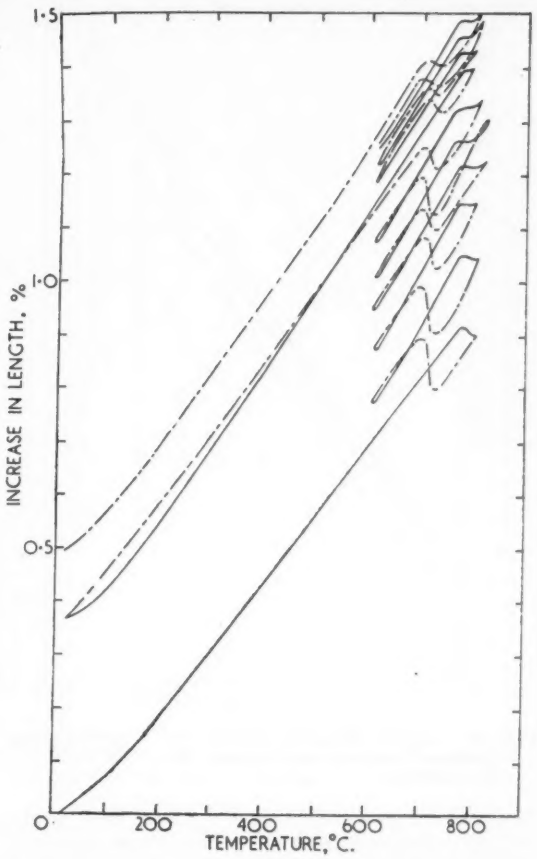


Fig. 29—Length changes in iron No. 2 during ten cycles of heating and cooling, 20° or 600° → 790° → 600° or 20° C. in ' vacuum '

similar curves for the other four irons are shown in Fig. 28*a*. The discontinuity in the curve for iron No. 4 is exceptional and may easily have been caused by some extraneous circumstance such as a disturbance of the apparatus overnight between the 2nd and 3rd cycles : the full test was not repeated since the magnitude of the disturbance was relatively small and the complete test takes more than 10 days.

The thermal critical ranges for the first heating and cooling are tabulated in Table X, but, in the families of curves typified in Fig. 27, a progressive lowering of the temperatures of the thermal critical ranges and the progressive decrease in the magnitude of the changes are generally apparent.

Ten Cycles, 600° → 850° → 600° C., in ' Vacuum '— Examination of Fig. 27 (and of the similar curves for the other four irons) indicated that very little growth took place at temperatures below 600° C., and it seemed that future tests might be shortened by cooling each time only to 600° C. instead of to room temperature. As a check, however, one of the irons (No. 2) was given a 10-cycle treatment to 850° C., in which seven of the cycles commenced at 600° C. The

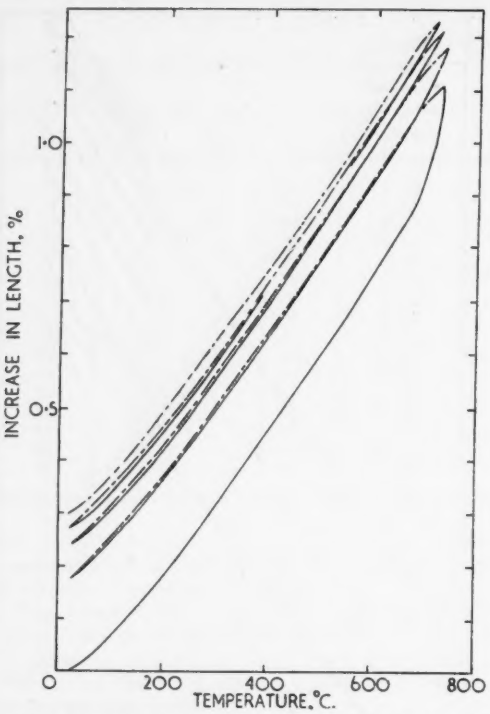


Fig. 30—Length changes in iron No. 1 during four cycles of heating and cooling, 20° → 730° → 20° C., in ' vacuum '

family of curves obtained showed a total final growth of 0·85% compared with 1·5% when the temperature limits were 20° C. and 850° C.

One Hundred Cycles, 600° → 850° → 600° C., in ' Vacuum '—The growth figures given in Fig. 28*a* showed interesting differences, but in practice an ingot mould may be used 100 or more times during its life, and it was considered advisable to determine whether the irons still showed the same relative order of growth if the test was extended to 100 cycles.

Controls were constructed that would automatically take the specimen through the required thermal cycle and photographically record the progress of growth both at 600° and 850° C. This 100-cycle treatment was carried out on the four irons Nos. 1, 2, 3, and 5 with results shown in Fig. 28*b*. Some oxidation of the specimens was noticeable after these tests. Each test lasted for approximately one week, and it is clear that during this time the small current of air in the equipment was having an effect, even although relatively low pressure was maintained.

Growth continued at an ever-decreasing rate, but even at the 100th cycle, the rate of growth was still measurable. The fact that the relative growths of the four irons lie in the same order of magnitude throughout the 100 cycles, and that they agree with the order of growth indicated by 10 cycles, 20° → 850° → 20° C. (Fig. 28*a*), justified the adoption of 10 as the number of cycles generally to be used in later tests of this type.

Table XI—GROWTHS (TOTAL, ISOTHERMAL, AND DURING HEATING AND COOLING) DURING ISOTHERMAL TESTS IN ' VACUUM '

Temp. of Test, °C.	Linear Growth, %															
	Iron No 1			Iron No. 2			Iron No. 3			Iron No. 4			Iron No. 5			
	T*	I†	H and C‡	T	I	H and C	T	I	H and C	T	I	H and C	T	I	H and C
600	+0·005	+0·035	−0·030	+0·05	+0·025	+0·025	+0·015	+0·03	−0·015	+0·05	+0·06	−0·01	+0·035	+0·025	+0·01
640	+0·16	+0·155	−0·005	..	..	..	+0·065	+0·105	−0·04	+0·135	+0·16	−0·025	..	..	..
650	..	..	..	+0·125	+0·115	+0·01	..	..	..	..	..	..	+0·115	+0·095	+0·02
670	+0·20	+0·22	−0·02	..	..	..	+0·205	+0·165	+0·04	+0·185	+0·24	−0·055	..	..	..
675	..	..	..	+0·52	+0·47	+0·05	..	..	..	..	..	..	..	+0·135	..
														+0·165	
700	+0·345	+0·355	−0·01	+0·53	+0·51	+0·02	+0·175	+0·175	Nil	+0·19	+0·325	−0·135	+0·18	+0·175	+0·005
730	+0·20	+0·16	+0·04	+0·53	+0·49	+0·04	+0·07	+0·025	+0·045	+0·265	+0·22	+0·045	+0·17	+0·14	+0·04
760	+0·265	+0·11	+0·155	+0·27	+0·19	+0·08	+0·15	+0·03	+0·12	..	..	..	+0·14	+0·13	+0·14
790	..	..	..	+0·16	−0·06	+0·22	..	..	..	..	..	..	..	Nil	..
850	..	..	..	+0·46	−0·03	+0·49	..	..	..	..	..	..	..	..	..

* T = Total growth
† I = Isothermal growth during 5 hr. at given temperature
‡ H and C = Growth occurring during heating to, and cooling from, the test temperature

Effect of Lower Top Temperature—Since 850° C. is above the thermal critical range of all the irons examined, a test was carried out to determine the growth when the specimen was heated to a maximum temperature within the thermal critical range, and a further test was included to determine the growth when heated to a temperature that was just sub-critical. The first of these was carried out on iron No. 2 heated to a maximum temperature of 790° C. ; the second was carried out on iron No. 1 heated to 730° C.

The total growth of iron No. 2 after 10 cycles, 600° → 790° → 600° C., in ' vacuum ' was 0·47%, *i.e.*, considerably less than when heated to 850° C. The complete family of curves is shown in Fig. 29. The test on iron No. 1 heated to 730° C. was carried out to ascertain how much growth was mainly attributable to sub-critical graphitization. The slope of the heating curves already obtained generally showed a distinct increase at temperatures just below the thermal critical range, and the degree of this increase varied with the heating rate, the slower the rate the greater being the increase in slope. This phenomenon has been noticed by other workers,[12] and is usually ascribed to sub-critical graphitization, *i.e.*, the conversion of carbide to graphite and ferrite at temperatures below the critical range. Iron No. 1 was chosen for this test, since it had exhibited this effect to the greatest degree. It was found that after the 2nd cycle the growth was fairly regular and small, and the test was therefore continued for four cycles only. The results are shown in Fig. 30, the final total growth being 0·31%.

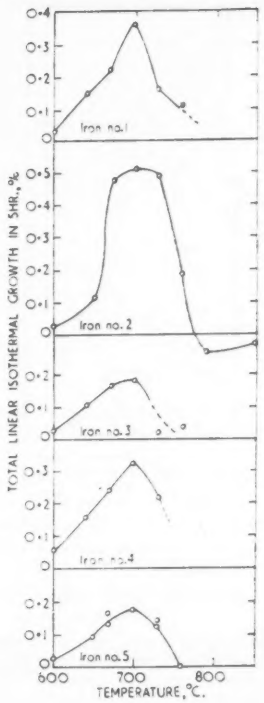


Fig. 32—Effect of temperature on total isothermal growth of irons Nos. 1–5 during 5 hr. in ' vacuum '

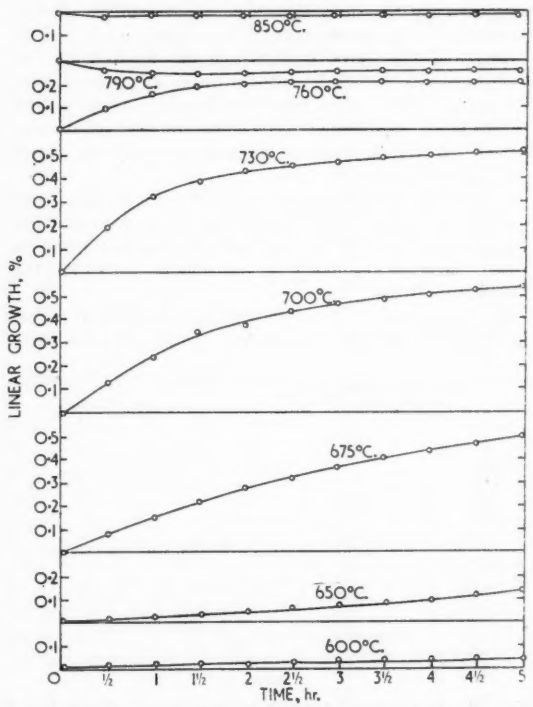


Fig. 31—Progress of isothermal growth of iron No. 2 in ' vacuum ' at various temperatures

Isothermal Tests

To investigate the progress of growth with time, tests were carried out in which the specimen was rapidly heated to a predetermined temperature, and the growth observed while the specimen was held at that temperature (in ' vacuum ') for 5 hr. The total growth of the specimen could be divided into two parts: (*a*) isothermal growth measured as already described, and (*b*) growth occurring during heating to, and cooling from, the isothermal treatment temperature. The latter is the difference between the isothermal growth and the total change in length of the specimen after treatment.

Such tests covering the range 600° C. to 850° C. were first carried out on iron No. 2. Figure 31 shows the development of isothermal growth at different temperatures ; the complete results are tabulated in Table XI, together with the results of subsequent tests on the other four irons. The isothermal growth/temperature curves for all five irons are shown in Fig. 32.

These results confirm the conclusion previously drawn from Fig. 27 and from similar curves, namely, that growth occurs mostly above 600° C. The most interesting feature of Fig. 32 is that, although the amount of growth varies from iron to iron, there is in all cases a maximum occurring over a fairly broad

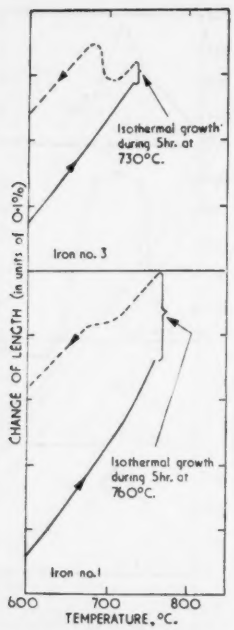


Fig. 33—Occurrence of a maximum or inflection in the length/temperature curve on cooling from a sub-critical temperature, in ' vacuum '

temperature range around 700° C. At higher temperatures the isothermal growth decreases until, in or above the thermal critical range, the isothermal growth is actually slightly negative, presumably because of the gradual attainment of true equilibrium by further $\alpha \rightarrow \gamma$ transformation and/or some resolution of graphite. During the cooling of an iron from isothermal treatment above 700° C. but below Ac_1, the cooling curves sometimes showed an expansion or inflection at approx. 700° C., indicating that sub-critical graphitization can take place to a substantial degree on cooling; examples are shown in Fig. 33 for iron No. 3 cooled from 730° C. and for iron No. 1 cooled from 760° C. This point will be referred to later when the mechanism of growth is discussed.

Tests were carried out to ascertain whether on repeating an isothermal test the rate of growth continued at the same rate as at the end of the previous test. During a second treatment of 5 hr. at 730° C., iron No. 2 showed a growth of 0·05% as compared with a growth of 0·50% during the previous similar treatment; the two growth curves in Fig. 34 show that the rate of growth during the second treatment agrees with an extrapolation of the first curve.

TESTS IN AIR

To prevent excessive oxidation of the specimen interfering with dilatometer results, all the work so far described had been carried out in ' vacuum ' and for the same reason it was thought desirable to carry out any standardized simplified tests under similar conditions. In practice, however, ingot moulds are exposed to the air, and a few tests were therefore carried out in air to ascertain whether the results were of the same order as those obtained under conditions of limited access of air.

Heating and Cooling Tests

Ten Cycles, 600° → 850° → 600° C., in Air—Heating and cooling tests in air were carried out on iron No. 2. The total growth was 1·12% in air as compared with 0·85% in ' vacuum,' and since part of the increased ' growth ' must be attributed to oxidation of the specimen, the agreement is generally satisfactory.

Isothermal Tests in Air

The isothermal growth characteristics of the same iron No. 2 in air were determined and are shown in Fig. 35, which may be compared with the corresponding curve in Fig. 32 for in ' vacuum.' It is seen that, particularly at 700° C. (a temperature of maximum growth), the growths in air and in ' vacuum ' are of the same general order, that in air being slightly greater, again probably because of oxidation of the specimen.

STANDARDIZED SIMPLE GROWTH TEST

The work so far described was considered to have established that :

(1) Tests may be carried out in ' vacuum ' (to avoid excessive oxidation of the specimen) without affecting the general order of the results obtained.

(2) The results of isothermal tests, as shown in Fig. 32, reflect the same general order of growth as repeated heating and cooling tests of the type shown in Fig. 28, *i.e.*, no iron showing a large growth by one test shows a small growth by the other, or *vice versa*, and if the irons are listed in order of the growth obtained by each test, the sequence is not different by more than one place for any iron. The repeated heating and cooling test is of course the more closely related to the type of thermal cycle experienced by an ingot mould in practice.

(3) The isothermal growth for each of the irons shows a fairly broad maximum in a temperature range close to 700° C., and tests at this temperature can therefore quickly discriminate between the different irons.

An isothermal test was therefore adopted to assess the relative growth characteristics of different irons

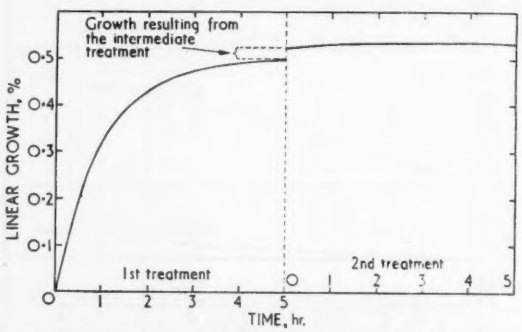


Fig. 34—Isothermal growth in ' vacuum ' of iron No. 2 during two successive periods of 5 hr. at 730° C. with intermediate cooling to 20° C.

within the range of the 16 irons under consideration. The test consists of rapidly heating a dilatometer specimen, under conditions of limited access of air, to 700° C., and measuring the growth while it is maintained at this temperature for 5 hr.

The results of this test on the whole series of 16 irons are shown in Table XII (second column).

Comparison between Growth found in Laboratory Tests and in Works Practice

A confirmation of the above results was given by the work carried out by B.I.S.R.A. (*see* p. 295) on the changes in length accompanying the annealing of two ingot moulds before use. The moulds were of the following analyses :

Mould No.	Si, %	Mn, %	S, %	P, %
SPT 880	2·07	0·65	0·057	0·046
SPT 888	1·26	0·64	0·049	0·150

Thus *SPT* 880 was very similar to iron No. 2 and *SPT* 888 was similar to iron No. 16 (*see* Table IX).

After a stress-relieving treatment of 6 hr. at 550° C., which caused virtually no change in length, the moulds were treated for 10 hr. at 700° C., and the following growths were observed :

Mould No.	Average Growth, %
SPT 880	0·65
SPT 888	0·35

Extrapolation of the results of the 5-hr. laboratory tests suggests that in 10 hr. iron No. 2 would have grown 0·6% (*see* Fig. 31) and iron No. 16 would have grown 0·3%. This shows satisfactory agreement with the figures obtained by B.I.S.R.A. and indicates that, even allowing for the difference between heating in air and in ' vacuum,' the growths obtained on the laboratory scale and those obtained during industrial heating are comparable.

Table XII

LIVES OF INGOT MOULDS

Iron No.	Growth Test Result, %	Mould No.	Mould Life, casts
1	0·35	371	146
		372	117
2	0·51	292	117
		293	129
3	0·17	200	169
		204	184
4	0·32	304	139
		305	135
5	0·17	173	141
		174	180
6	0·13	162	189
		163	107
7	0·11	148	124
		149	74
8	0·20	245	122
		246	147
9	0·18	269	100
		270	103
10	0·14	178	181
		181	106
		182	173
11	0·07	153	214
		156	139
		157	169
12	0·21	142	144
		143	150
13	0·22	195	144
		196	160
14	0·34	266	183
		267	185
		268	165
15	0·24	176	165
		177	87
16	0·16	183	149

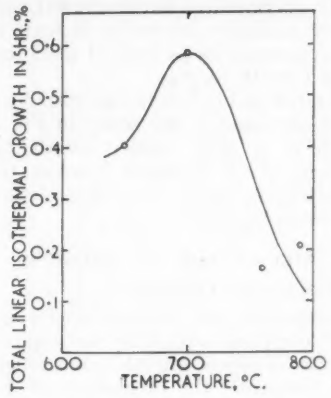


Fig. 35—Effect of temperature on isothermal growth of iron No. 2 during 5 hr. in air

Correlation between Chemical Composition and Growth Characteristics

Some attempt has been made to assess the effects of individual elements (C, Mn, Si, S, and P) on the growth characteristics given in Table XII (*i.e.*, growth in 5 hr. at 700° C. in vacuum).

Because of the many variable factors and the limited data available, the effect of composition cannot be assessed with any high degree of precision. No significant correlation between carbon (either total or combined) or sulphur, and growth could be found. For the remaining three elements Mn, Si, and P, it was found that the following relation gives a fair assessment of the susceptibility to growth over the range of analysis studied :

$$G = 0{\cdot}32 - 0{\cdot}21\,\mathrm{Mn} + 0{\cdot}13\,\mathrm{Si} - 0{\cdot}73\,\mathrm{P}$$

where G = Percentage isothermal linear growth in 5 hr. at 700° C. in ' vacuum,'

and Mn, Si, and P contents are expressed as percentages.

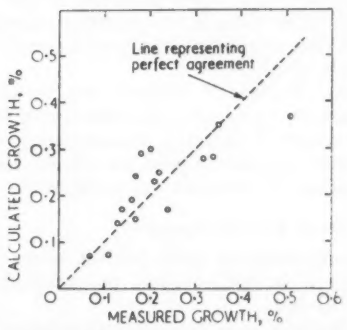


Fig. 36—Relationship between measured isothermal growth, during 5 hr. at 700° C. in ' vacuum,' and calculated growth

By a study of variance, the statistical significances of the above partial regression coefficients have been assessed as approx. 1 in 15 for P, 1 in 17 for Mn, and better than 1 in 100 for Si.

The measured and calculated growths for each iron are plotted one against the other in Fig. 36. The relationship is of only limited reliability, but is considered to be of sufficient interest to warrant re-examination for these and other elements when further data are available.

MECHANISM OF GROWTH

References to Earlier Literature

It is recognized that the reasons for growth are many and complex, and also that opinions differ widely on the causes of growth. According to Benedicks and Löfquist[13] the breakdown of 1·0% of C as carbide into ferrite and graphite will give about 0·68% linear growth, and *pro rata* for other carbide contents. Thus, any additional growth will be caused by some factor other than simple graphitization.

Three of the main reasons which have been advanced to explain growth other than by graphitization are :

(*a*) Oxidation effects
(*b*) The pressure of occluded gases
(*c*) Crack formation caused by differential expansion on heating and cooling through the critical range.

Rugan and Carpenter[14] concluded that growth is greatly increased by oxidation and is also affected by the presence of occluded gases. Andrews and Higgins[15] confirmed the importance of oxidation effects. Pearson[16] confirmed the main finding of the earlier workers, but also reported that in the complete absence of oxidizing influences, *i.e.*, in hydrogen, repeated heating and cooling gave rise to very little growth. On the other hand, Okachi and Satô[17] attributed growth mainly to the pressure of occluded gases, whilst Kikuta[12] stated that, on the first heating, growth was due to graphitization, but on subsequent heating it was attributed to the formation of fissures near the graphite flakes by differential expansion ; this growth was accelerated by oxidation.

Benedicks and Löfquist[13] developed a theory to explain the growth of cast iron by the irregular expansion and contraction of the iron on heating and cooling through the critical temperature range, causing fissures to develop. The presence of gas was not considered to be essential to growth although it was concluded that oxidizing gases would greatly increase the amount of growth.

In 1940, Timmins[18] studied the breakdown of pearlite in grey cast iron and confirmed that in itself this was mainly a diffusion phenomenon. He found that silicon did not appear to affect the rate of graphitization at constant temperature.

Evidence from Present Results

(1) During repeated cyclic heating tests, successive increments of growth became progressively smaller (*see* Figs. 27–30).

(2) The rate of growth became progressively slower during isothermal treatment (*see* Fig. 31).

(3) When an isothermal treatment below the Ac_1 temperature was interrupted by cooling to room temperature, the specimen reheated, and the test continued at the same temperature, growth continued at a rate similar to that immediately before the interruption (*see* Fig. 34).

(4) For all irons examined, the graphs of isothermal growth plotted against temperature show only slight growth at 600° C., no significant growth above the temperature of Ac_1, but a pronounced and fairly broad maximum at about 700° C. (*see* Fig. 32).

(5) Only four isothermal tests were carried out, on three different irons, at temperatures at or above that of Ac_1. Tests on iron No. 2 (thermal critical range 775–820° C.) at 790° C. and 850° C. both showed slight contraction during the first hour or two (*see* Figs. 31 and 32). A test on iron No. 5 (thermal critical range 760–780° C.) at the Ac_1 temperature of 760° C. showed virtually no change in length (*see* Fig. 32). The fourth test was on iron No. 3 (thermal critical range 755–770° C.) at 760° C. and only slight growth was observed (*see* Fig. 32).

For the other irons in Fig. 32 the curves, when extrapolated to higher temperature, could reasonably cut the zero-growth line at about the respective Ac_1 temperatures. There is thus considerable evidence that under the conditions of test, growth does not occur at temperatures above Ac_1. (Reference will later be made, however, to the profound effect which such heating of a ' grown ' iron can have on subsequent growth at lower temperatures.)

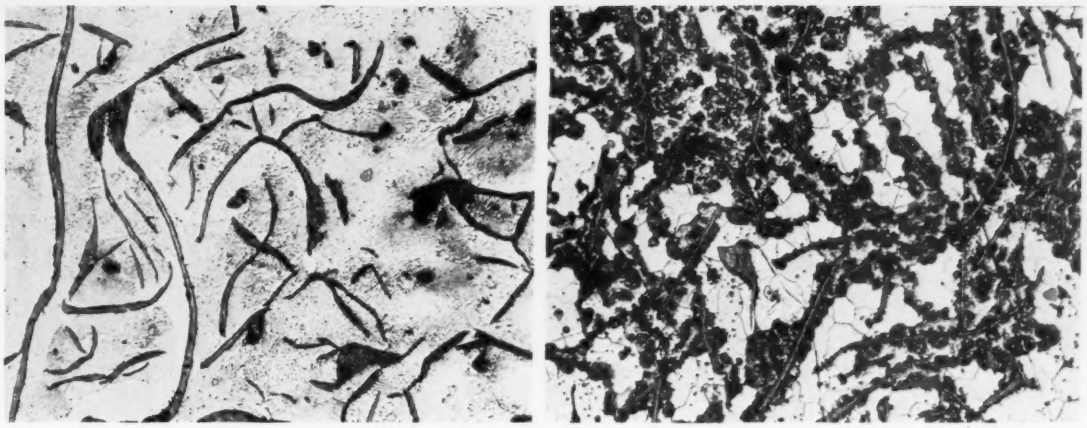
(6) When cooling after isothermal treatment at temperatures above 700° C. but below Ac_1, an expansion or inflection was sometimes noticed at about 700° C. (*see* Fig. 33). Since the iron had not been taken into the γ region, no $\gamma \rightarrow \alpha$ change could be involved, and it seems significant that this effect occurred in the same temperature region as does maximum isothermal growth.

(7) During two or three heating and cooling cycles into the γ region (850° C.), as much (or even more) growth can occur as during prolonged heating at any single temperature (*e.g.*, compare curves for corresponding irons in Figs. 28*a* and 32).

(8) The microstructure after cyclic growth compared with the microstructure before growth is typified by Fig. 37, which shows iron No. 2 before and after 100 heating and cooling cycles between 600° and 850° C. After cyclic growth the amount of combined carbon has decreased, with corresponding increase in the amount of free ferrite, and there is considerable deposition of secondary graphite around the original graphite flakes. Oxidation effects are also apparent.

(9) The microstructure of iron No. 1 before and after isothermal growth (5 hr. at 700° C.) is shown in Fig. 38. It is seen that :

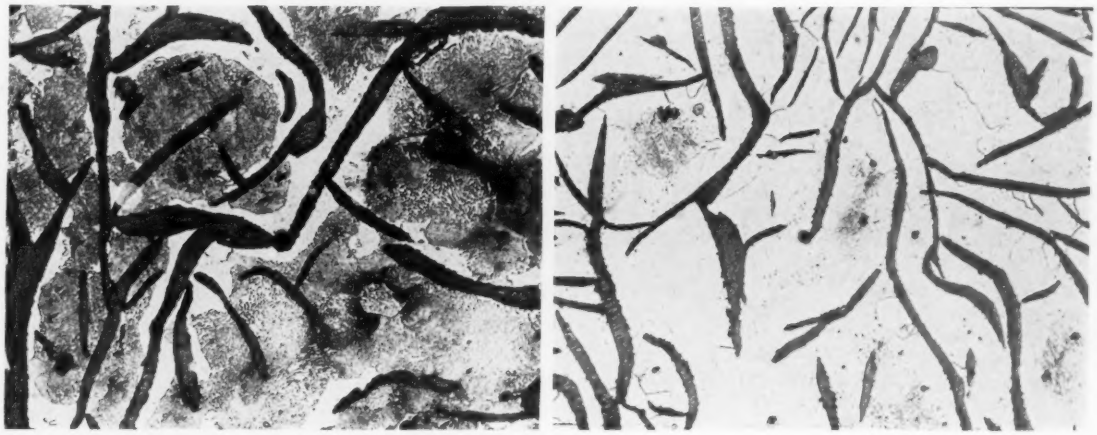
(i) The amount of combined carbon has decreased with corresponding increase in the amount of free ferrite (Figs. 38*a* and *b*)
(ii) Undissociated carbide is, in general, remote from the graphite flakes (Figs. 38*b* and *c*)
(iii) Deposition of secondary graphite occurs upon the original graphite flakes. Compared with Fig. 37, there is very little evidence of oxidation, no doubt chiefly because of the considerably shorter duration of these tests
(iv) After growth, the edges of the pearlitic areas are not sharply defined (Figs. 38*b* and *c*).



(a) As-cast

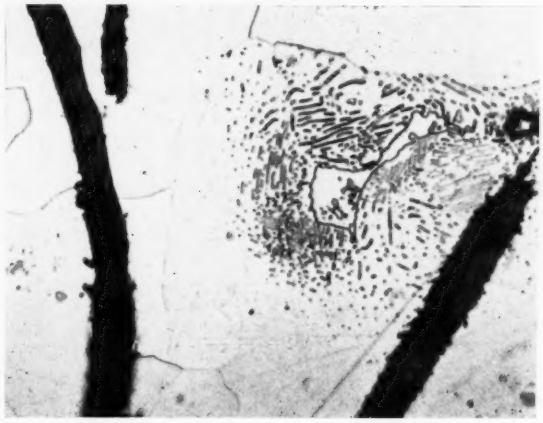
(b) After 100 cycles, 600°→850°→600° C. in ' vacuum '

Fig. 37—Microstructure of iron No. 2 before and after cyclic growth. Etched in picric acid × 155



(a) As-cast × 155

(b) After 5 hr. at 700° C. in ' vacuum ' × 155



(c) As (b) × 650

Fig. 38—Microstructure of iron No. 1 before and after isothermal growth. Etched in picric acid

(10) The pearlitic structure tended to persist around areas of phosphide eutectic, even when these were adjacent to graphite flakes. An example of this can be seen in Fig. 38*c*.

Theoretical Considerations

The following discussion is confined to the mechanism of the breakdown of carbide into ferrite and graphite.

In these tests this appears to have occurred by two distinct mechanisms. The first occurs at temperatures below Ac_1, and is typified by the isothermal tests of this type which have been described; the second occurs as a result of heating to a sufficiently high temperature for the $\alpha \rightarrow \gamma$ transformation (partial or complete) to occur. These two mechanisms will be considered separately.

Growth Below Ac_1—In cast irons that contain appreciable amounts of silicon, carbides are relatively unstable and tend to dissociate into α-iron and carbon. This carbon migrates through the ferrite matrix, and deposits as layers or 'tufts' of secondary graphite on the pre-existing graphite flakes. The first secondary graphite to be so deposited comes from the carbide areas near the graphite, and as graphitization progresses so the thickness of ferrite across which the carbon atoms have to diffuse to deposit on the graphite flakes, increases. This results in a decrease in the rate of graphitization, and hence a decrease in the rate of growth. Thus the progress of graphitization will be increasingly obstructed by a growing ferrite layer around the graphite flakes, but this effect may be slightly countered by the growth of small crystals of secondary graphite from the flakes into the ferrite layer.

The progress of graphitization will depend upon the mobility of the carbon atoms and the solubility of carbon in ferrite, and it is significant that maximum growth occurs in the temperature range in which α-iron has an increased solubility for carbon.

Below 600° C. there is very little growth and this could be attributed to lower mobility and solubility of carbon. No clear explanation has been found for the observed effect that growth decreases between about 700° C. and the Ac_1 temperature.

Eventually, the ferrite layer around the graphite flakes will grow to such a thickness that the carbon atoms can diffuse through it only extremely slowly, and further holding at the same temperature will produce little or no further growth. The only way further growth could be made to occur would be to reduce the thickness of the ferrite layer by a redistribution of the carbide throughout the iron. This may be achieved by a full anneal (*i.e.*, above Ac_3), as will be discussed later.

The tendency for pearlite to persist around areas of phosphide eutectic is in agreement with the negative regression coefficient found for phosphorus in the growth equation on p. 283, which is based on the results of a growth test below Ac_1.

Growth During Cyclic Heating into the γ-Region—Evidence was obtained that no growth occurred at temperatures above Ac_1 during periods up to 5 hr. On cooling from such temperatures, however, considerable growth occurred whilst passing through the thermal critical range (*see* Figs. 27 and 29).

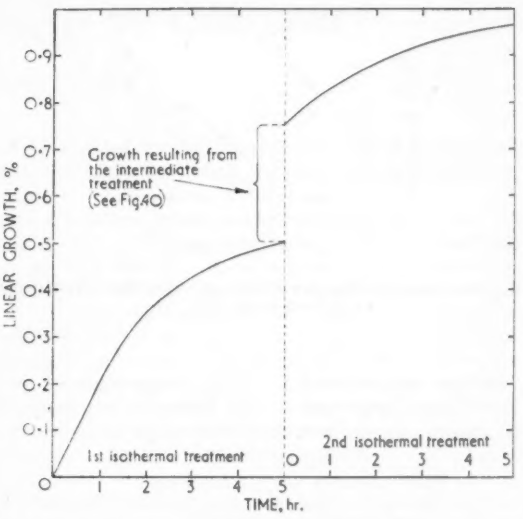


Fig. 39—Isothermal growth of iron No. 2, in 'vacuum,' during two successive periods of 5 hr. at 700° C. with intermediate treatment 700° → 850° → 20° → 700° C.

An explanation for this can be obtained from a consideration of the ordinary iron–carbon diagram; although these irons are not simple binaries the same principles may be applied. At the Ac_1 temperature, the pearlite transforms to austenite, which when heated to higher temperatures is not saturated with carbon in solution, and there is therefore no precipitation of graphite; in fact, there must be a tendency for solution of the graphite flakes (which is in accordance with the slight contraction noticed in some isothermal tests at such temperatures) although this is likely to be hindered by the slight oxide film that tends to form around the flakes, and which was evident in some of the present tests even under conditions of such limited access of air. Conversely, on subsequent cooling, this carbon will come out of solution at the Ar_1 temperature and will be partly precipitated as graphite, particularly from the austenite adjacent to the existing graphite flakes, which will act as nuclei, whilst the remainder transforms in the normal way to pearlite. During repeated cyclic treatment, there seems to be little re-solution of the graphite previously deposited, but there is a redistribution in the austenite of the carbon from the remaining pearlite, so that further graphitization can occur during the next cooling. Such growth can therefore continue during many cycles but its magnitude becomes progressively less because of the continuous decrease in the carbon content of the austenite.

Experimental Test of the Theory

If the suggested mechanism is correct, then it would be expected that an iron whose growth below Ac_1 was approaching a limit, would still be susceptible to cyclic growth. Also, after cyclic treatment, the iron should be capable of further growth below Ac_1 because of the redistribution of the remaining carbide.

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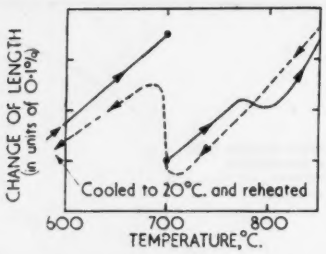

Fig. 40—Length changes during intermediate treatment referred to in Fig. 39

A test was devised in which a specimen of iron No. 2 was subjected to the following sequence of treatments in the ' vacuum ' dilatometer :

(*a*) Heated to 700° C.
(*b*) Maintained at 700° C. for 5 hr.
(*c*) Heated to 850° C., cooled to room temperature, and reheated to 700° C.
(*d*) Maintained at 700° C. for 5 hr.

The results, which are shown graphically in Figs. 39 and 40, indicate that marked further growth occurred during the cyclic treatment (*c*) and that there was a marked increase in the rate of further isothermal growth at 700° C., after the cyclic treatment, compared with the rate of isothermal growth immediately before the cyclic treatment. The total growth during the second isothermal treatment is less than that during the first treatment because less combined carbon was present, but it is much greater than would have been obtained without the intermediate full anneal (*cf.* Fig. 34).

These results are therefore in complete agreement with the theoretical suggestions.

It may be that all irons containing the same amount of combined carbon are potentially capable of the same amount of growth and that fundamentally it is only the rate of growth that is affected by chemical composition and microstructure.

SUMMARY AND CONCLUSIONS

(1) The growth characteristics of 16 irons used for the manufacture of ingot moulds have been examined at temperatures up to 850° C. A detailed preliminary examination of five of the irons indicated that in 5 hr. maximum growth took place at about 700° C., with little growth below 600° C., and with no growth above the Ac_1 temperature. It has, however, been shown that heating to temperatures above that of Ac_1 can greatly affect the amount of growth, which later takes place at lower temperatures.

(2) The measurement of the growth occurring in 5 hr. at 700° C. in ' vacuum ' was adopted as a measure of susceptibility to growth.

(3) Good agreement was found between laboratory growth tests and the growth resulting from the works-annealing of certain ingot moulds.

(4) Within the range of analysis studied, it was found that the growth under the conditions of the adopted test could be estimated with fair accuracy from the relation :

$$\text{Growth, \%} = 0{\cdot}32 - 0{\cdot}21\,\text{Mn} + 0{\cdot}13\,\text{Si} - 0{\cdot}73\,\text{P}$$

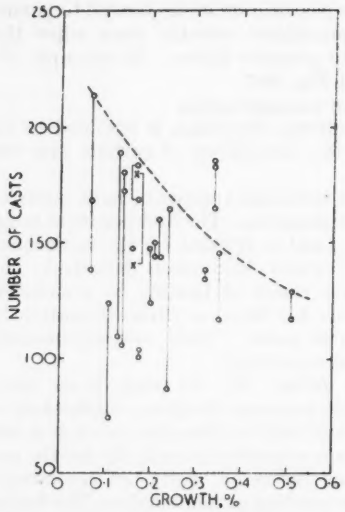

Fig. 41—Ingot mould lives plotted against the results of isothermal growth tests on samples of the same irons. Connected points refer to moulds from the same cast iron

(5) A suggested mechanism of growth by graphitization of carbide in cast irons of the types examined, which was based on the dilatometer work and on limited metallographic examination, was tested experimentally, and good agreement between the theory and the experimental results was obtained.

Acknowledgment

Acknowledgment is made to Mr. F. H. Saniter, Director of Research, The United Steel Companies, Ltd., for permission to publish this paper.

APPENDIX

Possible Correlation between Mould Life and Susceptibility to Growth

The records of ingot moulds (all 22½-in. semi-closed top), cast at the same time as the test blocks used in the work on growth described in this paper, have been examined for possible correlation between mould life and susceptibility to growth as measured by the isothermal growth test adopted. The figures are shown in Table XII, and are plotted in Fig. 41.

The large spread of the results, even in the lives given by different moulds made from the same cast of iron, indicates that any definite relationship between life and growth is completely masked by other factors (either inherent in the moulds themselves or associated with their use in the works) which, on the data available, cannot be separated.

The results given in Fig. 41 do, however, suggest that, if the highest mould life figures can be assumed to have been least affected by factors other than growth, then there is at least the possibility that, with these moulds, mould life decreases with increasing susceptibility to growth.

NOTE ON RELAXATION TESTS ON CAST IRON

By J. Woolman, M.Sc.

In view of the possible effect that growth might have on the stresses induced in cast-iron moulds during use, some relaxation tests have been carried out to determine the rate of relaxation of stress under constant deformation.

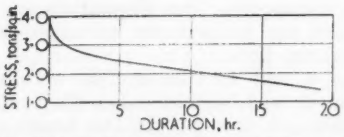

Fig. 42—Relaxation test on cast iron at 450° C.

The first test was carried out at 450° C. on a sample of iron No. 4. This was initially loaded at 4 tons/sq. in. and the load was then reduced manually by sliding the jockey weight of the testing machine along the beam by a hand wheel; the beam thus remained horizontal and the test piece was maintained at constant length. The resulting curve given in Fig. 42 shows that at 450° C. the stress relaxes quickly at first, but does not reach constant values even after 19 hr.

In a second test on a sample of the same iron at 700° C., the specimen immediately broke on reaching a load of 4 tons/sq. in. A repeat test was therefore carried out with an initial stress of 2 tons/sq. in. at 700° C., but the stress fell so rapidly that it could not be followed, and before a reading could be taken the specimen broke. The indications were, however, that the rate of relaxation was extremely rapid, so that it is unlikely that high stresses can build up at temperatures when growth of iron occurs. Thus it is improbable that growth can have any influence on the stresses induced in an ingot mould during use.

Paper SM/BA/85/49 of the Ingot Moulds Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 30th August, 1950.

Mr. Woolman, Chairman of the Stresses in Moulds Group, is at the Brown-Firth Research Laboratories.

DETERMINATION OF SURFACE STRESSES IN INGOT MOULDS

By M. W. Buttler, A.Met., A.I.M., and W. H. Glaisher, B.Sc., A.I.M.

SYNOPSIS

When a cast-iron ingot mould is filled with molten steel, stresses are produced in the walls owing to the steep temperature gradients set up. By measuring the consequent strains, it is possible to evaluate these stresses, if certain properties of the mould iron are known. The results of such tests are given and the possibilities of the stress causing failure of the mould by cracking are discussed.

The temperature cycle at various points in a mould, and the effect of heat-treatments designed (*a*) to promote growth of the mould iron, and (*b*) to determine the extent of residual stresses in the mould when cold, have been examined.

This work is an attempt to explain the failure of cast-iron ingot moulds by cracking, with a view to improving the design and increasing the life of moulds.

During teeming, the expansion of the inside surface of an ingot mould produces a tensile stress in the outer and cooler parts of the mould, the value of which attains a maximum at the external surface.[4]

The growth that occurs in ingot mould irons in the 650–750° C. range, may also set up stresses (*see* p. 281).

In this paper the problem of failure of moulds has been approached from two directions :

(1) By taking strain measurements at the surface of moulds during and after casting, and calculating the stresses indicated by the strains, and by taking further measurements at intervals throughout the life of the moulds

(2) By attempting to estimate the amount of growth that occurs in a mould, and its effect.

The possibility of preventing growth during service by suitable heat-treatment before use is also discussed.

MEASUREMENTS ON MOULDS

DETERMINATION OF SURFACE STRESSES

The method adopted for the estimation of surface stresses is based on the suggestions made by Land.[4]

Paper SM/BA/162/49 of the Ingot Moulds Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 30th August, 1950.

Mr. Buttler, formerly in the Steelmaking Division of the Association at Sheffield, is on the staff of Messrs. C. G. Carlisle and Co., Ltd., Sheffield. Mr. Glaisher is in the Steelmaking Division of the Association.

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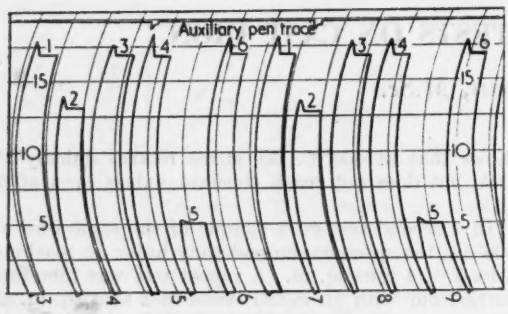

Fig. 43—Example of chart from temperature recording apparatus

At the surface layer of a mould the relation between stresses and strains is reduced to a two-dimensional problem. Any expansion of the mould surface is composed of two parts, that caused by the thermal stress and that caused by the thermal expansion of the surface. The practical problem, then, is to measure the total expansion along known gauge lengths in at least three directions during teeming, and to measure the surface temperature simultaneously. From the data obtained principal strains can be calculated.

To calculate the stresses occurring, from the measured strains, the following properties of the mould material must be known:

(i) The coefficient of linear expansion, so that the strain due to rise in temperature at the gauge site may be calculated

(ii) Poisson's ratio, to allow for stresses in planes at right angles to that in which strain measurements are made

(iii) Stress/strain curves at the relevant temperatures.

There are four main subdivisions of the work : the measurement of surface temperature ; the measurement of surface expansion ; data on the mechanical and physical properties of mould irons ; derivation of principal stresses from the measured strains.

Measurement of Surface Temperature

It is most important that the surface temperature of the mould be known accurately, since when the temperature is, for example, 300° C. the strain due to rise in temperature may be responsible for three-quarters of the measured strain. As the strain attributed to stress is the difference between measured strain and strain due to temperature, an error of a few degrees in temperature measurement causes a considerable error in the estimation of strain caused by stress. An automatic method for the accurate recording of temperature at two positions on each measuring site with an error not exceeding $\pm 2\%$ of the change of temperature, and with readings from each thermocouple every 5–10 sec., was therefore developed.

Base-metal thermocouples were attached by peening the small welded bead into a suitable hole in the mould surface, and the leads were connected to the recording apparatus, which comprised a thermocouple selector switch, D.C. amplifier, and high-speed recorder, and which has been described elsewhere.[19] A reading was obtained every 6½ sec. on each thermocouple. An auxiliary pen was fitted to the recorder, and by closing a remote-control switch a time correlation for strain-gauge readings was obtained on the chart used for temperature recording.

An example of the form of record obtained is shown in Fig. 43. The mould design in the first test and the location of the gauge sites are shown in Fig. 44. In later tests the moulds were of similar design but the inner faces were not corrugated. The moulds were all teemed through a tundish.

In the first test, four thermocouples were disposed around gauge site 2, 4 ft. from the bottom of the mould, and two around gauge site 3, 1 ft. from the bottom of the mould. This disposition was adopted to determine the temperature variation across the 5-in. dia. gauge sites.

In tests 3 and 4, two moulds were measured simultaneously, and, because only a six-point recorder was available, it was possible to locate only two thermocouples at the upper site and one at the lower. This was considered adequate because previous tests had shown that the temperature variation across each site was not great.

This series of tests showed that the temperature rise is fairly steady, and that accurate results could have been obtained with one thermocouple on each site, and by taking readings, say, every 30 sec.

It is considered, therefore, that in subsequent tests, where not more than two sites are being examined simultaneously, adequate temperature measurement can be obtained with a potentiometer. This makes it possible to carry out tests anywhere at short notice, and with little preparation.

Measurement of Surface Expansion

Practical Requirements—An error in any reading of total expansion will be introduced by the expansion of the instrument in contact with the hot surface of the mould. The instrument to be used, therefore, must either have a very small coefficient of linear

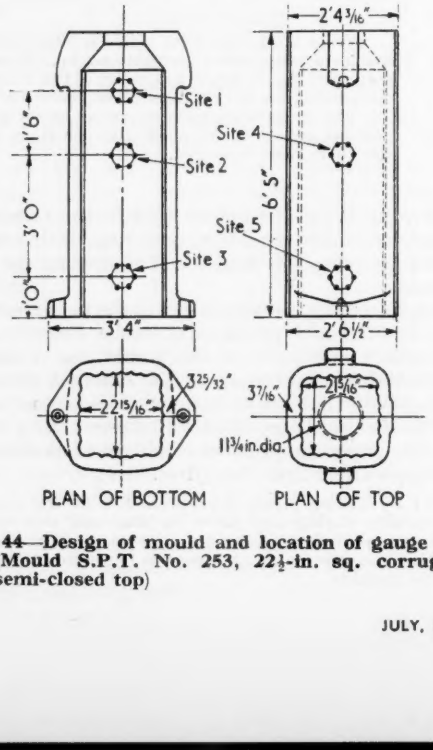

Fig. 44—Design of mould and location of gauge sites (Mould S.P.T. No. 253, 22½-in. sq. corrugated semi-closed top)

expansion, or a satisfactory means of correcting for temperature rise of the gauge must be available. It is desirable that a continuous record of total expansion in at least three directions about selected points be obtained for a gauge length of approx. 5 in. for general examination of large plane surfaces, and for a 1–2-in. gauge length near corners and at the free ends of the mould. In each case the gauge would measure the total expansion compounded of thermal expansion and strain due to thermal stress. In the ideal case, the gauges should be capable of remote recording to reduce dangers to the operator, who will otherwise have to be very close to the mould during teeming.

These requirements are not easy to satisfy under the particular test conditions. For example, wire resistance strain gauges, with small gauge lengths, would appear to be ideal for strain measurements at corners and near the ends of a mould, and equipment is available for recording from as many as 100 of these gauges. They could not be applied, however, in this case because it is extremely difficult to provide even moderately satisfactory compensation for the effect of temperature on the resistance of the gauges, which completely masks the resistance change caused by straining of the gauge.

Modified direct-reading Tomlinson strain gauges with 5-in. gauge lengths have been used in the present tests and, although neither continuously recording nor remotely controlled, the results obtained appear to be satisfactory.

Modified Tomlinson Direct-Reading Strain Gauge—A photograph of the instrument is shown in Fig. 45. The body consists of a 5¼-in. long channel section (of mild steel for the first test, but of low-expansion 36% Ni alloy for subsequent tests), to which is attached a dial gauge capable of reading to 0·0001 in. with a travel of 0·2 in., and two legs, one fixed and one movable. These legs carry 0·162-in. dia. steel balls which fit into carefully drilled countersunk holes in the mould surface. A plate carrying the fixed leg is attached to the underside of the channel by screws passing through slots parallel to the length of the channel, thus providing a coarse adjustment to the setting of the leg. The movable leg is attached to the other end of the channel through a collar and spring-steel strip, which functions as a hinge or fulcrum. The length of this leg is extended above the channel and the top end carries an adjustable hardened-steel screw with a flat tip, which bears against the round end of the dial-gauge stem. The position of this screw provides a fine adjustment for the zero reading of the instrument. The dimensions of this leg and its position are chosen so that movements of the base of the leg, caused by expansion of the mould surface, will give approximately equal movements in the dial gauge. A third leg is provided to give greater stability during the reading of the instrument. The handle and thumb rest enable the operator to transfer the gauge rapidly from one pair of drilled location holes to another. These holes were drilled with a ¼-in. dia. Slocum centre drill with a 60° taper and a ⅛-in. dia. lead, the total penetration being about $\frac{3}{16}$ in.

The gauge sites consist of three pairs of holes drilled to the desired tolerance on the circumference of a 5-in. dia. circle so that the three directions of expansion measurement were at 60°, as shown in Fig. 44. The thermocouples were attached to the mould surface, in each case, about ⅛ in. from the edge of one of the gauge location holes.

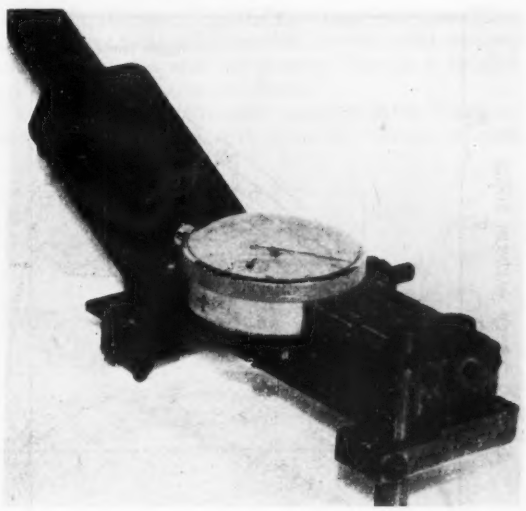

Fig. 45—Modified Tomlinson direct-reading 5-in. strain gauge

The location holes and the gauge legs were carefully cleaned to remove grease and dirt, which would affect the consistency of the readings. The sites were then tested with the gauge to ensure that consistent readings could be obtained in all directions. Cleaning and dressing of the location holes were continued until the readings were reproducible within one division (0·0001 in.). Two standard test plates were available, each having a pair of location holes accurately drilled at 5-in. centres. One test plate was placed remote from the mould but readily accessible to the strain-gauge operator, and the other in the mobile laboratory, which housed the 6-point thermocouple recorder. Frequent tests were made on the first test plate, the temperature of which varied slightly, and an occasional check test was made on the master plate in the laboratory.

Gauge readings for all directions on each site and on the test plates were taken immediately before the start of teeming. To obtain an exact time correlation for strain readings two operators were required, one to use the gauge and the other to note the readings and press the switch for operating the auxiliary pen in the recorder. This switch was also used to give a signal in the laboratory for starting the thermocouple selector switch and recorder motor and for indicating the start of teeming on the chart.

A definite sequence was adopted in taking strain readings. High speed of operation was essential to obtain a maximum number of readings in the time available. In general, about 13 min. after teeming it became impossible to take readings because the mould surface temperature had reached 350–400° C. and the mould could not be approached without extreme discomfort.

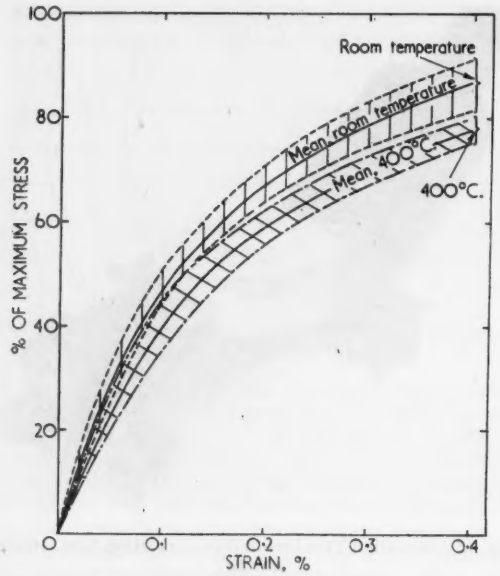

Fig. 46—Relationship between percentage strain and percentage maximum stress for various irons at room temperature and 400° C.

Mechanical and Physical Properties of the Mould Iron

As previously indicated certain fundamental data on the properties of the mould iron under test are required to derive principal stresses from the measured expansions and surface temperatures. The information required is : the mean coefficient of linear expansion, for the calculation of thermal expansion at the particular surface temperature ; stress/strain curves at various temperatures to determine the stress corresponding to a given strain at the required temperatures ; and Poisson's ratio for the temperatures and strains in question.

Because of the creep rate of cast iron at high loads, a further factor, which might be of importance in the analysis, was the effect of rate of strain on the stress/strain curve. It was also recognized that there might be appreciable differences in the values of these factors for different mould materials, although the basic trends in the effect of temperature, strain, etc., would probably be the same. To assess the importance of these effects, however, information on these factors for several mould materials would be necessary.

Coefficient of Thermal Expansion—An examination of the values given in the literature showed that the following average values could be taken as representative for a pearlitic mould iron :

0–100° C.	$1{\cdot}10 \times 10^{-5}$	in./in./° C.
0–200° C.	$1{\cdot}15 \times 10^{-5}$	,,
0–300° C.	$1{\cdot}20 \times 10^{-5}$	,,
0–400° C.	$1{\cdot}22 \times 10^{-5}$	,,

Stress/Strain Curves—Curves for various mould irons at room temperature and at 400° C., obtained by Grant (*see* p. 266), showed that the stress/strain characteristics of mould irons vary considerably. No curves were available for the particular iron of the moulds under test, but consideration of the various stress/strain curves (*see* Fig. 9) revealed that a given percentage strain represents about the same percentage of the breaking stress of any of the irons examined. This is shown in Tables XIII and XIV. The figures are shown graphically in Fig. 46 : the unbroken lines give the average percentage strain below 0·4% at both room temperature and 400° C., showing that the maximum error is less than 5% of maximum stress.

As the range of maximum stress of the iron studied is 5·4–10·3 tons/sq. in. at room temperatures, it seems reasonable to assume that these average curves will apply for most mould irons. Accordingly, the calculated percentage strains were applied to the mean curves in Fig. 46 and approximate figures for the percentages of maximum stress represented were obtained. Stress/strain relationships at temperatures between room temperature and 400° C. were obtained by interpolation between the two curves. To give some idea of the magnitude of the stresses set up, it was assumed that the stress/strain characteristics of the mould irons under test were the same as for iron No. 7 (*see* p. 266). Values for stresses obtained, using the above relationship, are plotted in Fig. 47.

Poisson's Ratio—As no definite value could be given for Poisson's ratio for the particular mould materials, and, at the time of the tests, no data were available to demonstrate the effect of temperature upon it, a constant value of 0·23 was assumed in the calculations of percentage strain.

Table XIII

STRESS/STRAIN RELATIONSHIP AT ROOM TEMPERATURE

Strain, %	Percentage of Maximum Stress				
	Iron No. 3	Iron No. 4	Iron No. 7	Iron No. 12	Iron No. 14
0·1	45·5	48	51	45·5	50
0·15	58	59·5	62	56	60
0·2	66	68	70·5	64	66·5
0·25	72·5	75	78	70	72
0·3	77·5	81	82·5	74·5	76·5
0·35	81	85	87	78	80·5
0·4	84	89	91	81·5	84

Table XIV

STRESS/STRAIN RELATIONSHIP AT 400° C.

Strain, %	Percentage of Maximum Stress				
	Iron No. 3	Iron No. 4	Iron No. 7	Iron No. 12	Iron No. 14
0·1	39	35	44	42	45
0·15	51	46·5	54	53·5	55
0·2	58	55	61	62	62
0·25	65	62	66·5	68	68
0·3	70·5	67·5	71	73	72
0·35	75	71	74·5	77	76
0·4	78·5	75	78·5	80	80

Derivation of Principal Stresses

The method used is described in the Appendix.

Summary of Tests

Each test was made on a new standard 22½-in. sq. semi-closed-top, small-end-up mould in the as-cast condition, corrugated in the first test, but plain-faced in the other tests. The moulds were isolated on their own base plates and top-poured through a tundish (in pairs in the latter two tests).

Strain measurements were taken in three directions at two sites (1 ft. and 4 ft. from the bottom) on each

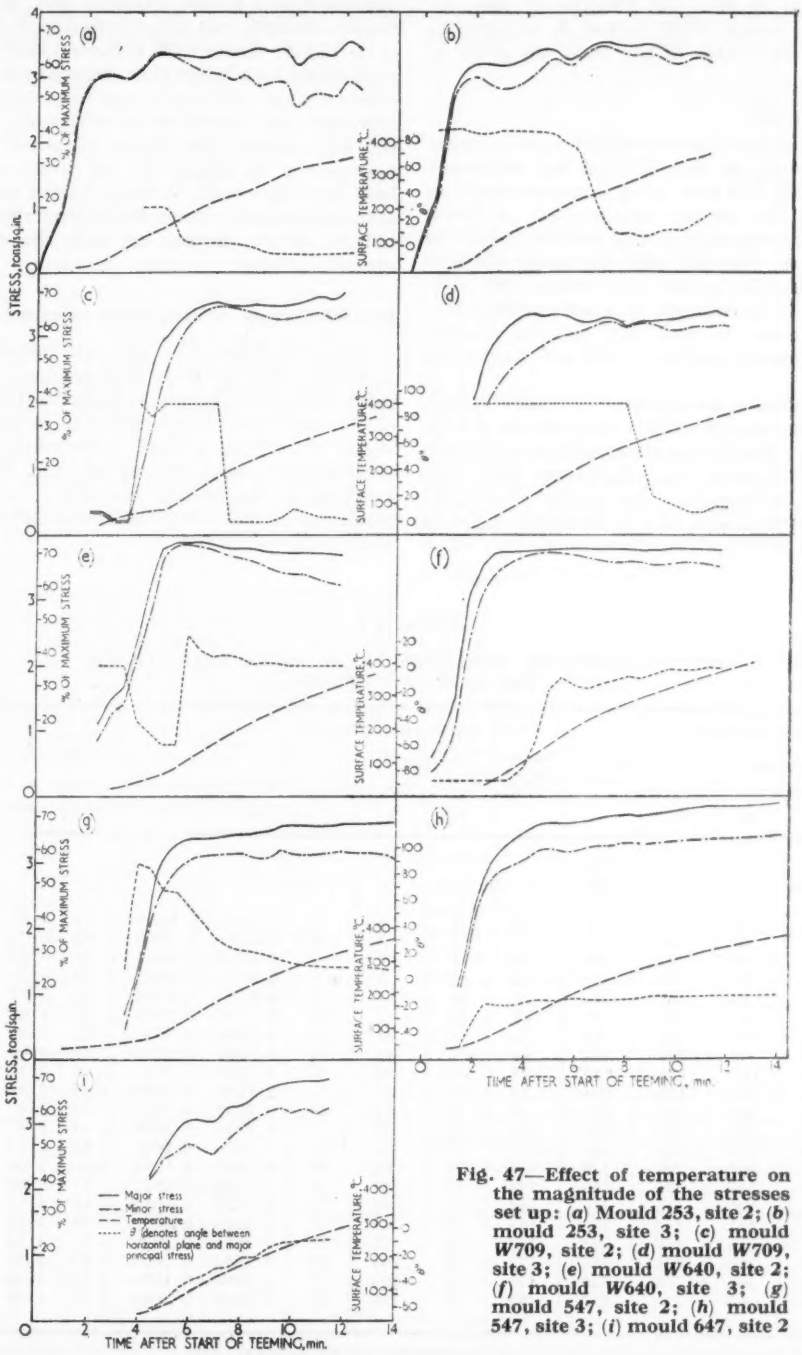

Fig. 47—Effect of temperature on the magnitude of the stresses set up: (*a*) Mould 253, site 2; (*b*) mould 253, site 3; (*c*) mould *W*709, site 2; (*d*) mould *W*709, site 3; (*e*) mould *W*640, site 2; (*f*) mould *W*640, site 3; (*g*) mould 547, site 2; (*h*) mould 547, site 3; (*i*) mould 647, site 2

mould under test. Surface temperature was recorded by means of the 6-point thermocouple recorder.

The actual strain and temperature readings taken were plotted, and from these curves the strain and temperature at ½-min. intervals were abstracted. Stress magnitude (assuming the stress/strain relationship to be as for iron No. 7) and direction were calculated from these figures. An example of this, for the upper site, mould *W*709 in test 3, is given in Table XV. Some details of the tests are given in Table XVI.

Discussion of Results

The graphs show that the stresses developed increase rapidly to between 60 and 70% of the maximum stress in the first 2–3 min. after commencement of teeming, while the surface temperature is below 100° C., and then remain more or less steady as the temperature rises. In each case the major stress is in a vertical direction in the early stages, but after 7–8 min. is mainly horizontal. It is not possible, from the available data, to find any definite relation between the composition of the mould and the stresses developed.

The results indicate the existence of relatively high stresses when the mould-surface temperature is high (above 300° C.). Land[4] suggests a much greater stress reduction with increase in temperature than has actually been determined. The biggest stress calculated was approx. 75% of the breaking stress in moulds 547 and *W*640, which allows only a very small margin of safety, particularly as the mould is subjected to repeated applications of stress during its service.

Repeated loading tests carried out by Grant (*see* Fig. 18*b*) showed that an iron with a maximum stress of 7·1 tons/sq. in. at 400° C. failed after 80 cycles under a stress of 5·5 tons/sq. in. or 77% of maximum stress. Samples of another iron withstood 150 applications of a stress equal to 85% of its ultimate tensile strength, but failed with a load equal to 94% of its U.T.S. Later tests indicated that if the load is maintained for a longer time in each cycle, even earlier failure occurs. Although these tests do not altogether reproduce the conditions of service of a mould, they provide evidence that failure of moulds by cracking may be due to fatigue. So far strain measurements have been taken only in the middle of the mould faces and, as cracks in these moulds generally begin near a bottom corner, it may be that the stresses there are even greater.

Possible Errors Arising from Incorrect Assumptions

Poisson's Ratio—For the calculation of stress, a constant value of 0·23 was assumed for Poisson's ratio. Since then, however, further tests for evaluation of Poisson's ratio have shown it to be more in the region of 0·15 (*see* p. 273). A few of the stresses were recalculated using this figure, and the maximum lowering of the results was 2%. In view of the smallness of this error the remainder of the figures were not recalculated.

Table XV

CALCULATIONS OF STRESSES FROM MEASURED STRAIN*
(Test 3; Mould *W*709; Site 2)

Time, min.	Measured Strain ($\frac{1}{10,000}$ on 5 in.)			Temp., °C.	Strain Due to Temp.	Strain Due to Stress ($\frac{1}{10,000}$ on 5 in.)			Strain, %		Stress, tons sq. in.		Angle Between Major Stress and Horizontal, °
	e_a	e_b	e_c			*a*	*b*	*c*	Major	Minor	Major	Minor	
0·5	...	...	...	22	...	...	...	...	...	...	...	...	...
1·0	...	...	...	22	...	...	...	...	...	...	...	...	...
1·5	...	...	...	22	...	...	...	...	...	...	...	...	...
2·0	5	5	5	27	2	3	3	3	0·0039	0·0039	0·35	0·35	...
2·5	10	10	10	36	7	3	3	3	0·0039	0·0039	0·34	0·34	...
3·0	16	16	16	50	15	1	1	1	0·0013	0·0013	0·22	0·22	...
3·5	21	21	21	60	20	1	1	1	0·0013	0·0013	0·22	0·22	...
4·0	40	28	40	67	24	16	4	16	0·0442	0·0182	1·49	0·77	90
4·5	62	41	74	74	28	34	13	46	0·1120	0·0493	2·75	1·64	−79½
5·0	82	63	82	82	32	50	31	50	0·1344	0·0930	3·03	2·48	90
5·5	104	90	104	103	44	60	46	60	0·1590	0·1286	3·24	2·90	90
6·0	126	117	126	127	58	68	59	68	0·1789	0·1593	3·40	3·24	90
6·5	148	142	148	153	74	74	68	74	0·1936	0·1808	3·49	3·39	90
7·0	166	162	166	178	88	78	74	78	0·2038	0·1950	3·53	3·47	90
7·5	179	181	179	200	106	77	79	77	0·2040	0·2000	3·49	3·47	0
8·0	190	195	190	219	114	76	81	76	0·2076	0·1966	3·48	3·42	0
8·5	199	207	199	235	124	75	83	75	0·2108	0·1933	3·50	3·38	0
9·0	206	218	206	250	134	72	84	72	0·2106	0·1847	3·47	3·30	0
9·5	214	229	216	266	144	70	85	72	0·2122	0·1814	3·48	3·27	+ 3½
10·0	224	241	230	280	153	71	88	77	0·2208	0·1882	3·51	3·32	+10
10·5	236	258	242	295	163	73	95	79	0·2356	0·1928	3·57	3·34	+ 7½
11·0	250	276	254	308	172	78	104	82	0·2552	0·2024	3·63	3·37	+ 4
11·5	250	281	255	320	178	72	103	77	0·2498	0·1872	3·58	3·26	+ 4½
12·0	265	306	270	333	187	78	119	83	0·2848	0·2004	3·71	3·55	+ 3

* Stress strain curve for iron No. 7 assumed to apply

Surface Temperature—The most likely source of error in the temperature measurements would be conduction of heat from the thermocouple junctions along the wires, thus giving a low reading. Under laboratory conditions this error was very small (0–5° C.), but, since under open-shop conditions it might be greater, errors of 10° C. and 20° C. have been assumed for the purpose of calculation in two instances. The effect of this assumption on the calculated stresses is as follows :

Recorded Temp., ° C.	Calculated Stress, %	Assumed Temp., ° C.	Calculated Stress, %
333	70	353	67
333	70	343	68½
82	56	102	48
82	56	92	52

It is therefore unlikely that errors in temperature measurement will be large enough to affect substantially the calculated stresses.

Coefficient of Expansion—Dilatation test results recently received from B.C.I.R.A. show that the coefficient of expansion α may vary according to the composition of the iron. A comparison between values obtained for irons Nos. 4 and 13 and those used in the calculations is as follows :

Temp. Range, ° C.	α, in./in./° C. Iron No. 4	Iron No. 13	Used in Calculations
0–100	$0{\cdot}9 \times 10^{-5}$	$1{\cdot}00 \times 10^{-5}$	$1{\cdot}10 \times 10^{-5}$
0–200	$1{\cdot}05 \times 10^{-5}$	$1{\cdot}17 \times 10^{-5}$	$1{\cdot}15 \times 10^{-5}$
0–300	$1{\cdot}15 \times 10^{-5}$	$1{\cdot}215 \times 10^{-5}$	$1{\cdot}20 \times 10^{-5}$
0–400	$1{\cdot}20 \times 10^{-5}$	$1{\cdot}25 \times 10^{-5}$	$1{\cdot}22 \times 10^{-5}$

Because of heterogeneity, values obtained for different specimens of the same iron may also vary, and it is very difficult to obtain a figure which will be representative of the iron of a particular mould.

The figures used in the calculations were probably on the high side for the lower temperature ranges but were about average in the 0–400° C. range. The error in the calculated stress is greatest in the 0–100° C. range, and for a mould surface temperature of 100° C. the calculated stresses would be as much as 10% low, if the actual coefficient of expansion of the mould iron were $0{\cdot}9 \times 10^{-5}$ in./in./° C. The magnitude of the error decreases at higher surface temperatures, and at 300° C. may be only $\pm$ 2%.

Creep—In the stress figures given, no allowance has been made for the small amount of strain due to creep of the material. Short-time creep can be estimated from Grant's figures (*see* p. 267) for creep occurring in the first 5 min. under load at room temperature and at 400° C. The load applied to the most comparable iron, No. 7, was 3·5 tons/sq. in. and is approx. equal to the stress already calculated to occur during most of the first 12 min. after teeming (if it is assumed that the stress/strain curves for No. 7 iron apply).

At this stress, the amount of creep occurring in 5 min. was 0·005% at room temperature and 0·024% at 400° C. The following initial creep rates have, therefore, been assumed :

Temp., ° C.	Creep Rate, % per min.
20	Nil
100	0·001
200	0·001
300	0·002
400	0·005

Assuming these rates to apply over the first 12 min., the total creep occurring in this time can be estimated as follows :

Creep Time, min.	Mean Temp., ° C.	Creep, %
0– 3	40	Nil
3– 6	120	0·003
6– 9	240	0·003
9–12	310	0·006
	Total creep	0·012

If total creep is deducted from the calculated strain (due to stress), a calculated stress of 0·1 ton/sq. in. lower (*i.e.*, 2% of the maximum stress of the iron) is obtained.

STRAIN MEASUREMENTS DURING THE LIFE OF MOULDS

Method

Four of the test moulds, *W*640, *W*709, 547, and 647 were measured in three directions about five selected points (*see* Fig. 44) at intervals during their lives. The moulds were temporarily withdrawn from service after one and after approx. 10 and 20 lives, and after each succeeding 20 lives, and were measured with the Tomlinson gauge when cold. Unfortunately many of the sites were damaged by splashing during casting.

General Survey of Results

Measurement after the first life showed a slight contraction in most cases, but this was not evident after 8–12 lives. The top site, 1, remained very close to the original dimensions for the complete life, whereas the middle sites, 2 and 4, showed expansions of up to 25×10^{-3} in. per 5 in. (about 0·5%) after

Table XVI

PARTICULARS OF MOULDS USED IN STRAIN-MEASUREMENT TESTS

Test	Mould No.	Maker	Mould Analysis, %					Calculated Stress given in Fig. Nos.
			Total C	Si	Mn	S	P	
1	253	*X*	...	1·00	0·49	0·09	0·157	47*a* and *b*
3	*W*709	*Y*	3·49	1·26	0·73	0·054	0·166	47*c* and *d*
3	*W*640	*Y*	3·67	1·64	0·90	0·039	0·049	47*e* and *f*
4	547	*X*	...	1·12	0·91	0·058	0·163	47*g* and *h*
4	647	*X*	...	2·17	0·94	0·034	0·045	47*i*

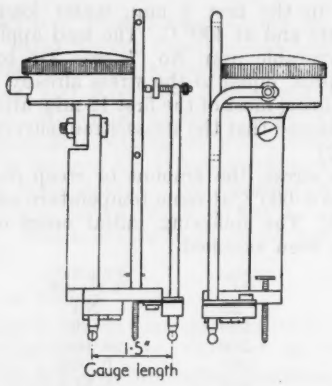

Fig. 48—Modified direct-reading 1½-in. strain gauge

approx. 40–50 lives, and generally this was maintained until failure. The bottom sites, 3 and 5, were damaged by casting splashes, and no definite results were obtained. The greater expansion of sites 2 and 4 could be expected because they reach a higher temperature than the others and therefore grow more.

Even after 100 lives the measured strain was only 0·5% at the most. If the preceding calculations of creep during each life are approximately correct, then the strain after 100 lives should be approx. 1·2% due to creep alone. Further small amounts of strain due to growth of the iron and to permanent set after being stressed in tension, were also to be expected. It is thought that, on cooling, the outside surface of the mould is under compression, and there will, therefore, be some creep, but this is expected to be very small because irons are much more rigid in compression.

As no actual mechanical properties of the mould irons in question are known, it is very difficult to advance any theory as to why the total strain after a number of lives is much lower than anticipated. It may be that some of the irons are much stronger than iron No. 7 on whose properties the calculations of strains due to creep have been based. However, if it is only a question of comparative creep resistance, it is difficult to explain the fact that there is no great variation in measured strain between the moulds although the chemical analyses are very different.

On two moulds, which were annealed before use (*see* later) to allow growth to occur, the measured strain during subsequent life was smaller (0·24%) for a low-silicon content, but of the same order (0·45%) for a high-silicon mould as that of unannealed moulds. This suggests that the major part of the expansion occurring during life is due to causes other than growth.

STRESS-RELIEVING OF MOULDS

This was carried out to determine whether stresses are set up during manufacture of the moulds, and whether there are any residual stresses after use. Such stresses might have a cumulative effect, so that during casting the total stress acting might be close to the ultimate stress of the mould iron.

Examination of the literature[20] on the stress-relief of cast iron showed the optimum treatment to be a 6-hr. soak at 600° C., during which 97·5% of any stress present would be relieved. However, it has been shown (*see* p. 279) that at 600° C. some growth occurs which may confuse the issue. The moulds were, therefore, stress-relieved by soaking at 550° C. for 6 hr. At this temperature no growth occurs and about 90% of stress present is relieved.

Two new moulds of the following analyses were used :

	Si, %	Mn, %	S, %	P, %
Mould No. 880	2·07	0·65	0·057	0·046
,, ,, 888	1·26	0·64	0·049	0·15

They were drilled at five sites as for the other strain-measurement tests, and after measurement they were given a stress-relief treatment at 550° C. for 6 hr. followed by furnace cooling. No significant changes were found on remeasuring, indicating that no stresses were present after manufacture.

These moulds were then annealed (as described on p. 295) and after they had been used once in the normal way they were given a stress-relieving treatment as before. Measurement both before and after this treatment showed that no significant dimensional changes had occurred either as a result of one usage or of the stress-relieving treatment.

The same stress-relieving treatment was also given to moulds 547 (1·12% Si, 0·163% P) and 647 (2·17% Si, 0·045% P) after they had had approx. 70 lives. There were definite dimensional changes, both expansion and contraction, but the results on one mould bore very little relation to the results on the other, *e.g.*, site 5, mould 647, contracted, but the same site on mould 547 expanded. Until more data are available, therefore, it is impossible to explain the results.

The least change occurred consistently at sites 2 and 4 on each mould. The possible explanation for this is that, as these sites attain the highest temperatures during casting, a large proportion of any stress acting at the time is relieved.

DEVELOPMENT OF A SMALLER GAUGE

It is clear that at some positions in moulds there is the possibility of local stress concentration. At such positions there may be quite a large stress variation along a 5-in. gauge length and only average strain will be measured by the present type of gauge even if it is possible to apply it. To measure strain at such positions, a gauge was designed on the same principle as the present type, but with a 1½-in. gauge length as shown in Fig. 48. It was constructed of 36% Ni low-expansion alloy, except for a spring-steel strip to provide a fulcrum ; the magnification factor was made 5 : 1 in an attempt to obtain even greater accuracy.

The original plan was for three of these gauges to be attached in delta formation to the mould during casting, and to be continuously photographed. Trials with this method were unsuccessful owing to the errors introduced by the rise in temperature of the gauge itself. This was not unexpected and a thermocouple was attached to one gauge so that the error in the readings caused by rise in temperature could be calculated. Unfortunately, however, the expansion

of the spring-steel strip introduced further errors, which were above the permissible limit.

Non-reproducible results were obtained when applying the 1½-in. gauge intermittently, owing to the difficulty of obtaining a firm seating. Attempts are therefore being made to modify the design for intermittent use and to eliminate the spring-steel strip for continuous measurement.

GROWTH OF MOULD IRONS

Tests carried out by Heselwood and Pickering (*see* p. 281) showed that isothermal growth does not vary directly with temperature, but occurs most rapidly in the temperature range 650–750° C., with a maximum growth of about 0·5% after 5 hr. at 700° C. Therefore, in an ingot mould during casting, there will be differential growth throughout the walls, due to the various temperatures attained, and this difference in growth will either set up stresses or cause distortion.

ANNEALING OF MOULDS BEFORE USE

It was thought that if the moulds could be soaked for sufficient time at the temperature of maximum isothermal growth, a high proportion of the possible growth would occur throughout the walls, and the likelihood of stresses being set up by differential growth would be reduced.

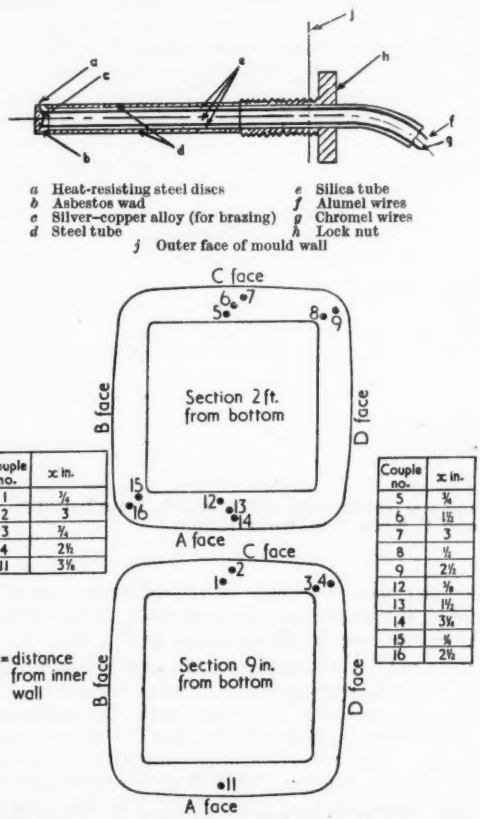

Fig. 49—Type of hot junction employed and its location in mould

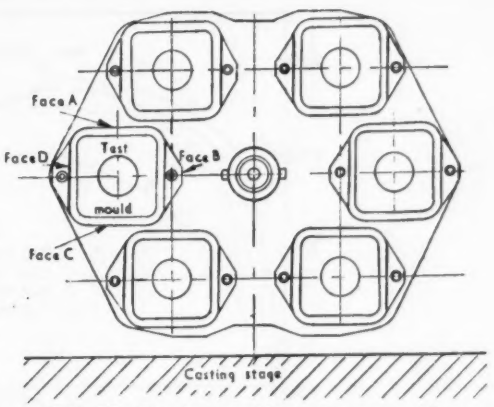

Fig. 50—Casting position of test mould

To examine this theory, moulds 880 and 888, which had been given a stress-relieving treatment, as previously described, were annealed at 700° C. for 10 hr. and furnace-cooled. Measurements at five sites were taken before and after the treatment and showed expansions of 0·5–0·8% (average 0·61%) on the high-silicon mould 880, and 0·3–0·37% (average 0·35%) on the low-silicon mould 888.

The results obtained by Heselwood and Pickering in laboratory tests on specimens of similar irons were comparable with these figures, particularly for mould 880. Extrapolation of the curves (Figs. 34 and 35) shows that a growth of 0·67% could be expected from a 10-hr. soaking at 700° C. in air of the high-silicon iron. The only figure available for the low-silicon iron is 0·16% growth after 5 hr. at 700° C. in 'vacuum'.

These moulds failed after lives of 76 and 80, although the average life of this type of mould is normally about 140. This suggests that any beneficial effect on mould performance due to the reduced amount of growth occurring had been outweighed by other changes in the iron, possibly the main one being a lowering of the tensile strength. During the life of the annealed moulds, further expansions varying from 0–0·45% occurred at the gauge sites, and although the figures were very inconsistent, they were of the same order as those which occurred in unannealed moulds. There is a possibility that in the annealed moulds a greater proportion of this strain was due to creep, and less to growth.

It is now thought to be unlikely that growth sets up any stresses in the mould, since at the temperatures at which growth occurs—650–750° C.—relaxation is very rapid.

TEMPERATURE SURVEY OF A MOULD

To estimate the growth in a mould in practice it is necessary to have a knowledge of the temperatures in the mould walls during and after casting. Tests were carried out on a 22½-in. semi-closed-top mould of the type used for the strain-measurement tests.

Method

The method adopted for the measurement of temperature within the walls was basically the same

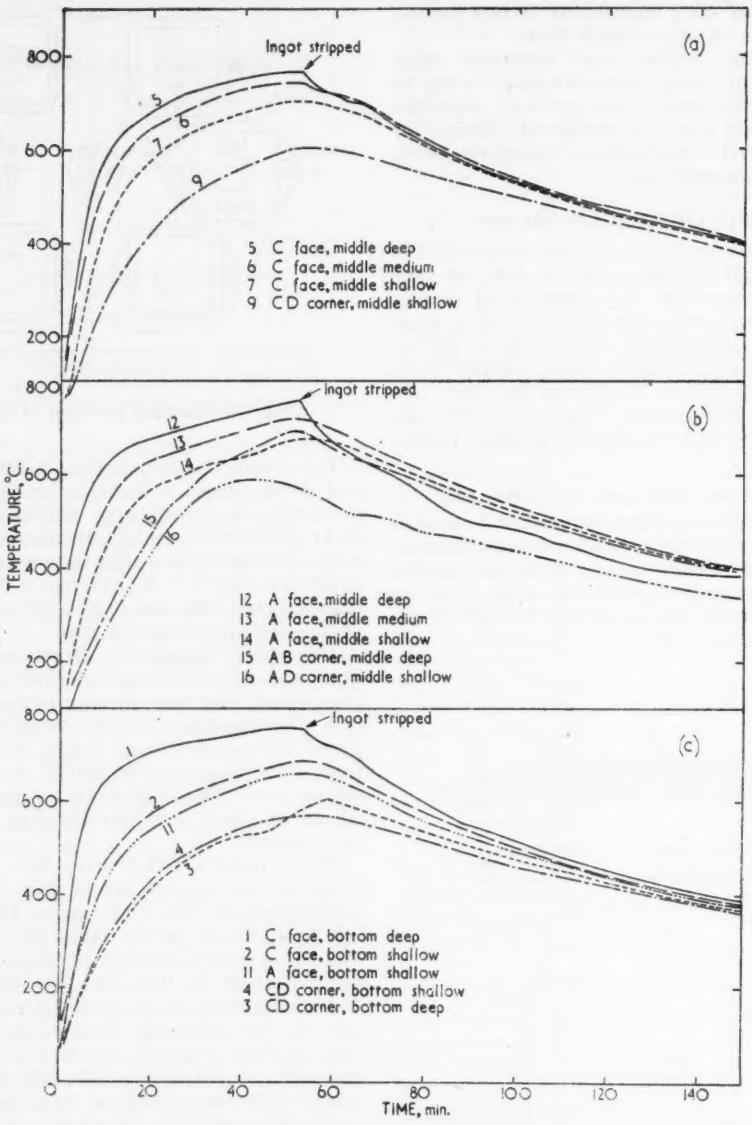

Fig. 51—Time/temperature curves on 22½-in. semi-closed-top test mould: (*a*) C face, 2 ft. from bottom; (*b*) A face, 2 ft. from bottom; (*c*) A and C faces, 9 in. from bottom

as that described in the Second Report of the Ingot Moulds Sub-Committee.[1]

A new mould was used to ensure easy stripping so that temperature measurements could be continued after stripping. The analysis of the mould used was :

Total Carbon, %	Si, %	Mn, %	S, %	P, %
4·00	1·04	1·16	0·054	0·107

With the apparatus available only 16 couples could be used at once, and it was therefore important to locate them in the positions that would yield the most information. As the main cause of failure in this type of mould is by longitudinal cracking, commencing near a corner at the bottom end of the mould, it was decided to concentrate on this area and the mould was drilled as shown in Fig. 49.

The holes were made as small as practicable ($\frac{5}{16}$ in. dia.) to minimize interference with normal heat conditions in the wall, and were made flat-bottomed to make better contact with the disc hot junction of the couple. The type of couple employed is shown in Fig. 49, and consists of 28-S.W.G. chromel and alumel wires brazed on to a $\frac{1}{16}$-in. thick, $\frac{1}{4}$-in. dia. mild steel disc. The use of this type ensured that any loss of heat from the hot junction along the couple wires would be

negligible compared with the heat content of the disc. By using the mild-steel tubes it was possible to force the disc into close contact with the bottom of the hole by tightening the bolt. The 16 couples used were connected through a multipoint switch to a direct-reading indicator. This instrument was calibrated for use with a maximum external resistance of 20 ohms but, owing to casting-pit conditions, long couples of 70 ohms resistance had to be used. The indicator was, therefore, recalibrated immediately before and after use by means of a potential divider.

The test mould was set up in the usual way on a 6-way plate in the position indicated in Fig. 50 and normal casting procedure was followed. After 55 min. the mould, with couples still attached, was stripped from the ingot and stood on the floor. Each couple was switched on in turn and readings were taken continuously until, approx. 2½ hr. after casting, all couples were reading less than 400° C.

Results

Figure 51 gives the time/temperature curves for all the couples, and from these the curves in Fig. 52 have been drawn to show the temperature gradient through the wall at various times during the heating and cooling cycle.

Figure 53 is an attempt to show from the limited data a time/temperature distribution through the complete cross-section of the mould at the level of the couples. Although somewhat conjectural, it shows that parts of the mould never reach a temperature at which rapid growth occurs (650° C.) while other parts remain above this temperature for a considerable time at each use. It also shows the influence of the position of the mould on the plate.

An attempt has been made to calculate the amount of growth which will occur at three points during one use of a mould of a given composition. It has been assumed that the temperature distribution, found in the test reported, would be the same whatever the composition of the mould, and, as an example, the composition has been taken to be that for iron No. 2 (*see* Tables VIII and X). The positions taken were numbers 5, 7, and 9 of Fig. 49, and the figures are as follows :

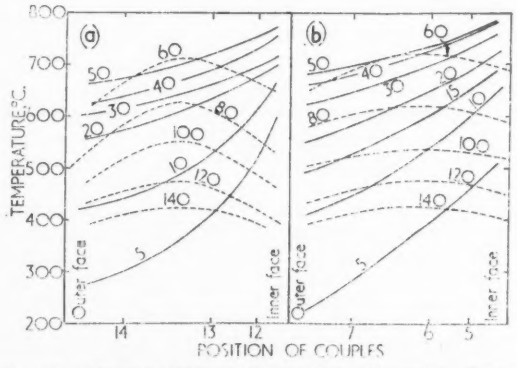

Fig. 52—Temperature gradient through walls of test mould: (*a*) Middle of C face, 2 ft. from bottom; (*b*) middle of A face, 2 ft. from bottom. (Figures on curves give time in min. after commencement of cast)

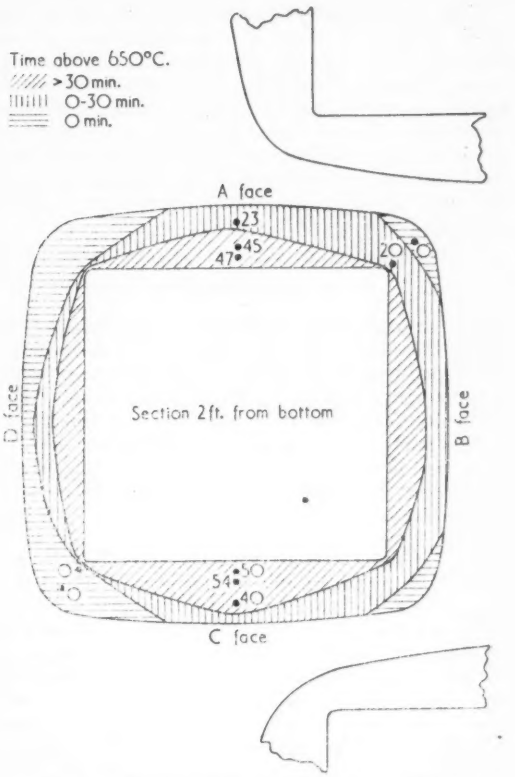

Fig. 53—Time/temperature distribution through the complete cross-section of the test mould at the level of the thermocouples

No. 5 Couple (C Face, Middle, Deep)

Temp. Range, °C.	Time in Range, min.	Mean Growth in 5 hr. in this Range, %	Calculated Growth, %
600–650	13	0·07	0·003
650–675	8	0·29	0·008
675–700	9	0·49	0·014
700–730	15	0·50	0·025
730–760	16	0·34	0·018
Above 760	11	Nil	Nil
Growth in heating to 770° C. and cooling			0·11
		Total	0·178

No. 7 Couple (C Face, Middle, Shallow)

Temp. Range, °C.	Time in Range, min.	Mean Growth in 5 hr. in this Range, %	Calculated Growth, %
600–650	20	0·07	0·005
650–675	12	0·29	0·012
675–700	20	0·49	0·032
700–730	8	0·50	0·013
730–760	Nil	0·34	Nil
Growth in heating to 710° C. and cooling			0·025
		Total	0·087

No. 9 Couple (C–D Corner, Shallow)

Temp. Range, °C.	Time in Range, min.	Growth in 5 hr. at 600° C., %	Calculated Growth, %
600–605	12	0·025	0·001
Growth in heating to 600° C. and cooling			0·025
		Total	0·026

These figures can, of course, be used only as very rough indications, since the conditions are not the same as those used in Heselwood and Pickering's tests. They do, however, indicate that considerable growth occurs at some points in the mould even during one usage, while at other points the growth is very much less. The differences in growth calculated above would set up large stresses in the moulds were it not that growth occurs only at temperatures at which relaxation is rapid.

CONCLUSIONS

(1) A satisfactory method for strain measurement and subsequent stress calculation has been developed. To obtain numerical values for the stresses occurring it is necessary to know the stress/strain characteristics of the actual mould iron examined. In the absence of this information it is possible to estimate the stress as a percentage of the ultimate tensile strength, and so obtain the necessary information without the properties of the particular iron under test being known.

In the moulds examined, the stresses set up at points on the centre-line of a face were found to be about 70% of the breaking stress of the irons on single loading, and to be much closer to the strengths of the mould irons obtained in repeated loading tests of 150 cycles duration. These figures go some way to explain both the occasional cracking of some types of mould at the first use, and the frequent cracking of others after a considerable number of lives.

The actual strengths of the irons of the moulds examined are not known, and it is likely that they do not cover the range of properties reported on p. 264, although the range of analysis covered is quite wide. It is possible that, with high-strength irons such as No. 3, lower percentage stresses will be found.

(2) Strain measurements made at intervals throughout the lives of four moulds yielded inconsistent results, but showed that permanent expansion of up to about 0·5% occurs at the hotter parts of the outer surface, and that little or no permanent expansion occurs at a cooler position near a lug. However, no relation between strain and composition could be found.

(3) Stress-relief annealing both of new moulds (as-cast) and of the same moulds after one use in the steelworks showed no significant dimensional changes, suggesting that residual stresses are small.

(4) Two moulds, annealed before use to allow part of the growth to occur, showed surface expansions of 0·3–0·8%. These were of the same order as the expansions found in growth annealing tests on small specimens of the same compositions reported by Heselwood and Pickering (*see* p. 280). The beneficial effect hoped for by annealing was not obtained, the moulds failing after comparatively short lives, and showing similar permanent expansions to normal moulds.

(5) A temperature survey of a mould during use showed that certain parts of the mould did not attain the minimum temperature for rapid growth (650° C.), while other parts remained in the temperature range for most rapid growth for a considerable period.

The effect of this growth on the cracking of moulds is probably small, since it occurs at temperatures above 650° C., when the mould iron is in a plastic condition. It may, however, be a contributory factor to crazing of the inner surface of moulds.

FUTURE WORK

The most profitable line of future work is in the determination of stresses both at further points in the type of mould already examined, and in other types of mould. Comparison of these stresses should yield useful information on the effect of certain design factors, such as wall thickness or the presence of internal corrugations, on the liability of moulds to cracking.

It is important for this work that an instrument of smaller gauge length be developed (*see* Fig. 48), and work on the 1½-in. gauge will be continued. It is also hoped to carry out tests on a series of moulds known to cover the normal range of iron properties.

Acknowledgments

The authors thank Mr. N. H. Bacon of Messrs. Steel, Peech and Tozer for providing field test facilities for the trials; Mr. H. E. Dixon, formerly with B.I.S.R.A., now with the British Welding Research Association, who developed the testing technique used and carried out the first full-scale test; and Mr. D. I. Bell of the Steelmaking Division, B.I.S.R.A., for assistance in many of the tests carried out.

APPENDIX

Derivation of Principal Stresses

Determination of Surface Stresses

For two perpendicular axes X and Y lying on the mould surface

$$e_x = \bar{\alpha}\theta + \frac{\sigma_x}{E_x} - \frac{\rho\sigma_y}{E_y} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

and

$$e_y = \bar{\alpha}\theta + \frac{\sigma_y}{E_y} - \frac{\rho\sigma_x}{E_x} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where

e_x = total strain along axis X
e_y = " " " " Y
E_x = stress/strain ratio at stress σ_x
E_y = " " " " σ_y
$\bar{\alpha}$ = mean coefficient of thermal expansion over range of temperature 0–$T°$ C.
$T°$ = surface temperature of mould
ρ = Poisson's ratio

whence

$$\frac{\sigma_x}{E_x} = \frac{e_x + \rho e_y}{1-\rho^2} - \frac{\bar{\alpha}T}{1-\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

and

$$\frac{\sigma_y}{E_y} = \frac{e_y + \rho e_x}{1-\rho^2} - \frac{\bar{\alpha}T}{1-\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

and these equations show that the magnitude of the thermal stresses may be calculated.

Derivation of Principal Strains

The following sequence of operations was adopted for the analysis :

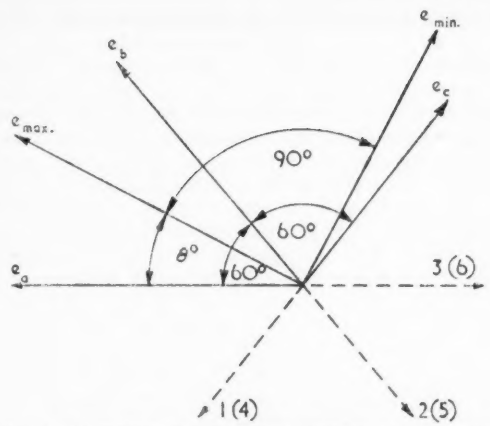

Fig. 54—Direction of measured strains and principal strains

(1) Interpolation of measured expansion and corresponding surface temperature at ½-min. intervals
(2) Calculation of thermal expansion of mould on 5-in. gauge length at specific temperatures
(3) Subtraction of calculated thermal expansion from total measured expansion to determine strain on 5 in. due to thermal stress.

If e_a, e_b, and e_c are the strain values (corrected for thermal expansion) in directions *a*, *b*, and *c* (*see* Fig. 54), then the maximum and minimum principal strains, e_{max} and e_{min} respectively, are given by the relations

$$e_{max} = A + B \quad \ldots\ldots(5)$$

and

$$e_{min} = A - B \quad \ldots\ldots(6)$$

where

$$A = \frac{e_a + e_b + e_c}{3} \quad \ldots\ldots(7)$$

and

$$B = \frac{e_a - A}{\cos 2\theta} \quad \ldots\ldots(8)$$

Where θ, the angle between the horizontal plane and and the maximum principal stress, is derived from the expression

$$\tan 2\theta = \frac{3}{1 + 2\,\frac{e_a - e_b}{e_b - e_c}} \quad \ldots\ldots(9)$$

Derivation of Principal Stresses from Principal Strains

From equations (3) and (4)

$$\sigma_{max} = \frac{E\sigma_{max}}{1 - \rho^2}\left(e_{max} + \rho e_{min}\right) \quad \ldots\ldots(10)$$

and

$$\sigma_{min} = \frac{E\sigma_{min}}{1 - \rho^2}\left(e_{min} + \rho e_{max}\right) \quad \ldots\ldots(11)$$

and from equations (5) and (6)

$$\sigma_{max} = \frac{E\sigma_{max}}{1 - \rho}\left(A + B\,\frac{1 - \rho}{1 + \rho}\right) = \frac{E\sigma_{max}}{1 - \rho}\,(A + B') \quad \ldots(12)$$

and

$$\sigma_{min} = \frac{E\sigma_{min}}{1 - \rho}\left(A - B\,\frac{1 - \rho}{1 + \rho}\right) = \frac{E\sigma_{min}}{1 - \rho}\,(A - B') \quad \ldots(13)$$

where

$$B' = B\,\frac{1 - \rho}{1 + \rho}$$

If Poisson's ratio = 0·23 (assumed constant for the temperatures and strains involved) then

$$\sigma_{max} = E\sigma_{max}\left[1{\cdot}3\,(A + 0{\cdot}626\,B)\right] \quad \ldots(14)$$

$$\sigma_{min} = E\sigma_{min}\left[1{\cdot}3\,(A - 0{\cdot}626\,B)\right] \quad \ldots(15)$$

In these equations A and B are in in./in.

GENERAL DISCUSSION

From the preceding sections it will be seen that the principal effort of the Group has been directed towards the determination of the stresses set up in a practical case, rather than to the extension of the purely mathematical work. For this purpose, it has been necessary to amplify considerably the data on the properties of mould irons, and to make strain measurements on moulds in service. Although the whole of the data required by Land[4] for the mathematical work has not been obtained, the knowledge of the behaviour of mould irons is now sufficient for some assessment of stress from measured strains to be made.

All the strain measurements reported here were made on new moulds, and this limits, to some extent, the conclusions that can be drawn. It was shown in laboratory tests, however, that if a specimen of mould iron is heated to a temperature of 620° C. after stressing, the stress/strain characteristics on a subsequent loading are similar to those on the first loading: without this intermediate heat-treatment, very different characteristics are obtained on second loading. It remains for speculation, however, what happens to the loading curve, the breaking strength, and the total elongation at fracture of the iron after many applications of stress followed by this heat-treatment.

In practice, of course, large parts of any mould reach temperatures above 620° C. on each use, while other parts may not reach this temperature. If the material reaches the fully annealed state, its tensile strength falls considerably.

Paper SM/BA/37/50 of the Ingot Moulds Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 30th August, 1950.

A further limitation to be borne in mind when considering the data is that the mechanical tests were all carried out at fixed temperatures. In the mould itself, both the temperature and the stress vary at the same time, and therefore the conditions are not the same. Tests have shown that the rate of loading has some influence on the stress/strain curve, but the differences at the different loading rates used are probably no greater than differences caused by heterogeneity in the irons.

The stress figures reported were originally calculated on an assumed stress/strain curve, which will not be truly representative of the iron of all the moulds, and their numerical accuracy must therefore be in doubt. Buttler and Glaisher have shown, however, that for all the mould irons examined there is an almost constant relationship between stress and strain, if the former is expressed as a percentage of the ultimate tensile strength of the particular iron. It is therefore possible to state with more confidence that, in use, the particular mould examined was subjected, at the points tested, to stresses of about 70% of the ultimate tensile strength of the iron, without knowing exactly what that ultimate stress was. The likelihood of error in the calculation of these stresses has already been discussed (*see* p. 292) and it is possible that were all the errors involved in the same direction they would amount to about 15% of the stress figures obtained. Thus it can only be said that the stresses at the points of measurement reach a level of between 60% and 80% of the strength of the mould material. These stresses, even if applied only once to the mould material, do not give a large margin of safety, since irregularities of surface or the presence of small cavities or of unusually irregular graphite distribution will tend to cause stress concentrations above the level of those measured.

The margin is even smaller when it is remembered that in repeated loading tests mould irons have been found to fail after about 80 cycles when subject to stresses of about 80% of the ultimate strength obtained in a static test. Thus the figures obtained for the points at which strain measurements were made suggest that the stress at these points is very close to the limit which the mould material will stand, and it is clear that in these circumstances the design of the mould used is not one that gives sufficient margin of safety to prevent completely the occurrence of cracking. It is unlikely that the particular positions selected for the strain measurements were those at which the greatest stresses occurred, since in practice the type of mould used generally fails by cracking near a corner. It was not convenient to place the 5-in. Tomlinson gauge near corners, but it can be assumed that the stresses there must have been greater than those at the measured positions.

If a picture of stress distribution over the whole mould could be obtained, the effects of variation of design could be studied, and eventually the design of moulds could be put on a sounder basis. With the development of the small gauge it is hoped that this result will be achieved.

A relationship between ingot mould composition and the growth of the iron has been shown by Heselwood, who suggests that the compositions that give least growth are those that are known to give, on the average, the longest mould lives. It was not possible, however, to relate the growth of the actual irons measured to the performance of the moulds from the same casts, because the number of tests was small. It is thought that, if any relation between susceptibility to growth and mould life exists, this must be a secondary effect and not caused by stresses induced by the growth. For example, the strengths of the irons may be affected in different degrees by heating to the temperatures at which growth occurs.

CONCLUSIONS AND FUTURE WORK

CONCLUSIONS

THE main conclusions reached in each paper of this Symposium can be summarized as follows :

(1) Examination of the mechanical properties of ingot-mould irons has shown that :

(*a*) The ultimate tensile strength varies between 5 and 10 tons/sq. in. at room temperature and it does not fall with increasing temperature until above 400° C.

(*b*) Under repeated loading conditions, a load equivalent to 80% of ultimate tensile strength can cause failure of a specimen after 80 cycles.

(2) The values obtained for Poisson's ratio on a number of ingot-mould irons at three temperatures are much lower than those generally assigned to cast irons.

(3) Relaxation of stress in ingot-mould irons is exceedingly rapid at temperatures of approx. 700° C. and probably at temperatures of 600° C. and above.

(4) Dilatation tests have shown that :

(*a*) Maximum isothermal growth of ingot-mould irons occurs at 700° C. with little growth below 600° C. and none above the Ac_1 temperature

(*b*) The amount of growth occurring in 5 hr. at 700° C. can be regarded as a measure of susceptibility to growth

Paper SM/BA/38/50 of the Ingot Moulds Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 30th August 1950.

(*c*) Growth occurring in this standard test can be estimated from the relation:

$$\text{Growth, } \% = 0{\cdot}32 - 0{\cdot}21\ \text{Mn}\% + 0{\cdot}13\ \text{Si}\% - 0{\cdot}73\ \text{P}\%$$

(*d*) There are indications that mould life decreases as susceptibility to growth increases.

(5) Stress measurements on ingot moulds have shown that:

(*a*) The actual values of the stresses set up during teeming can be determined only if certain properties of the particular mould material, *e.g.*, stress/strain curves at room temperature and at 400° C., Poisson's ratio, and the coefficient of linear expansion, are known. On the other hand, it has been shown that for all the mould irons examined there is an almost constant relationship between stress and strain if the former is expressed as a percentage of the ultimate tensile stress of the particular iron.

(*b*) Stresses equivalent to approx. 70% of the ultimate tensile stress of the mould irons have been calculated from strain measurements made at two positions on one design of mould, during and after teeming. This stress approaches closely the 'endurance' strength of the mould materials and it is thus not surprising that the moulds tested frequently fail by cracking.

No further mathematical work on the calculation of stresses from the mechanical and thermal properties of moulds has been carried out. To carry out any such calculations additional mechanical test data up to at least 800° C. would be required and, even with these data, the calculations would prove extremely difficult because of the difficulty of taking into account plastic deformation and relaxation of stress with time, at elevated temperatures. It is, therefore, not proposed to pursue this method of dealing with the problem at the present time.

FUTURE WORK

It is intended to extend strain measurements and stress calculations to cover other positions in the moulds, and thus to determine at which points stress concentrations occur.

Similar tests and calculations will be carried out on moulds differing in various details (*e.g.*, different wall thicknesses, corner radii, and contours). Later, other aspects concerning mould design will be considered. For such work to be satisfactorily carried out it is essential to have an improved strain gauge to span a much shorter length than 5 in. The 1½-in. gauge at present being developed will go a long way to meet this need.

From this work it is hoped to obtain data from which it will be possible to design moulds that will not fail by cracking, without sacrificing other desirable properties. Where possible, mechanical tests will be carried out on test samples of iron cast at the same time as the moulds under investigation, so that the properties of the actual mould shall be known.

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NEWS

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Meetings

Special Meeting in Austria

Details of the Special Meeting in Austria, to be held from **5th–19th September, 1951,** were given in the February and May issues of the *Journal*.

Autumn General Meeting

The Autumn General Meeting of the Institute will be held in London on **21st–22nd November, 1951.**

Changes on Council

The following have accepted invitations to serve as Honorary Members of Council:

Professor A. J. MURPHY, M.Sc., President of the Institute of Metals

Mr. A. B. ASHTON, M.Sc., President of the Manchester Metallurgical Society

Mr. E. T. GILL, President of the Sheffield Metallurgical Association

Mr. F. E. PROBYN, President of the Ebbw Vale Metallurgical Society.

NEWS OF MEMBERS

▶ Mr. T. A. BANFIELD has transferred from the Barking Laboratory of British Paints, Ltd., to the Newcastle-upon-Tyne Laboratory of the same firm.

▶ Mr. J. B. BOOKEY, of the British Iron and Steel Research Association, has been awarded the Ph.D. degree of the University of London.

▶ Mr. F. W. A. CARPENTER has resigned from the Boards of Messrs. Bird and Co., Ltd., and Messrs. F. W. Heilgers and Co., Ltd., of Calcutta, and will join the Board of Messrs. Bird and Co. (London) Ltd.

▶ Dr. G. P. CONTRACTOR, formerly Assistant Director (Planning) for the establishment of the National Metallurgical Laboratory of India, has been appointed Acting Director of the Laboratory, in succession to Professor Charles Crussard.

▶ Mr. T. A. COSH of Jarrow Tube Works, Ltd., has been awarded the B.Sc. degree of the University of Glasgow.

▶ Mr. F. DEVINE has left Messrs. W. and T. Avery, Ltd., and is now with Mufulira Copper Mines, Ltd., Northern Rhodesia.

▶ Mr. N. N. GHOSH has retired from his position as chemist and metallurgist with the Indian State Railway Service to become a Consultant in Calcutta.

▶ Dr. V. J. D. HILL has resigned his position as Manager of the Electric Welding Division of Thermal Welding Products, South Africa, and has been appointed Manager of Quasi-Arc, South Africa.

▶ Mr. H. HOFFSTEDT has taken up an appointment at Ab Asea Svetsmaskiner, Arc Welding Laboratory, Stockholm.

▶ Mr. J. G. HOLMES has left Forster's Glass Co., Ltd., St. Helens, to take up an appointment with the Michelin Tyre Co., Ltd., Stoke-on-Trent.

▶ Mr. J. T. KEMP is on leave from the American Brass Company and is serving on the staff of the Defence Minerals Administration, U.S. Bureau of Mines.

▶ Mr. M. C. LLOYD, Director and General Manager of the Weldless Steel Tube Co., Ltd., has joined the Board of Directors of Messrs. F. H. Lloyd and Co., Ltd., Steel Founders, of Wednesbury.

▶ Mr. J. MCCRACKEN has left Messrs. Stewarts and Lloyds, Ltd., to take up an appointment as General Manager with the Indian Iron and Steel Co., Ltd. and The Steel Corporation of Bengal.

▶ Mr. I. P. MCDOWALL has joined the Department of Research and Technical Development, Messrs. Stewarts and Lloyds, Ltd., Coatbridge.

▶ Mr. H. L. O'CONNOR has resigned his position as Blast-Furnace Manager with Messrs. Stewarts and Lloyds, Ltd., Corby, to take up an appointment as Superintendent of Blast-Furnaces and Coke Ovens with the Indian Iron and Steel Co., Ltd., Bengal.

▶ Mr. J. G. PARR of the Department of Metallurgy, University of Liverpool, has been awarded a Nuffield Foundation Scholarship. He is spending four months visiting metallurgical centres in Canada.

▶ Mr. J. W. PARSONS has left the Steel Castings Division of B.I.S.R.A., to take up a research grant sponsored by the Ministry of Supply at the Refractories Department of the University of Sheffield.

▶ Mr. D. V. REDDI has taken up an appointment with the Inspectorate of Metal and Steel, Ishapore, India.

▶ Mr. P. W. SMITH is now attached to the technical staff of Murex (Australasia) Pty., Ltd.

▶ Mr. C. R. TIPTON is now at the Battelle Memorial Institute, Columbus, Ohio.

▶ Mr. E. T. TURKDOGAN has been awarded the Ph.D. degree of the University of Sheffield for research work carried out under a grant from the Andrew Carnegie Research Fund. He has now joined the Research Staff of the British Iron and Steel Research Association.

Obituary

Mr. H. SMITH, Director of the Coppee Company (G.B.) Ltd., on 5th May, 1950. It is regretted that this information has only now been received.

Mr. A. COOKE, formerly Technical Director, Appleby-Frodingham Steel Co., Ltd., Scunthorpe, on 30th April, 1951.

Mr. W. S. WOOD, Works Director of Messrs. James Royston Son and Co., Ltd., in February, 1950. It is regretted that this information has only now been received.

Mr. J. R. YOUNG, on the Administrative Executive Staff of the Broken Hill Proprietary Co., Ltd., Newcastle, N.S.W., on 5th January, 1951.

Mr. O. H. WASS, Chief Sales Representative of General Refractories, Ltd., Sheffield, on 20th April 1951.

CONTRIBUTORS TO THE JOURNAL

F. B. Pickering, L.I.M.—On the staff of the Research and Development Department of The United Steel Companies, Ltd. Mr. Pickering was educated at King Edward VII School, Sheffield, and joined The United Steel Companies, Ltd., in 1943 as a junior assistant in the Physics Laboratory of the Research and Development Department. He attended evening classes at Sheffield University and was awarded the Associateship in Ferrous Metallurgy and the Mappin Medal in 1948.

J. W. Grant

F. B. Pickering

Since 1950, he has been employed in the microscopical section of the Metallurgical Department of the Companies' Research and Development Department.

M. W. Buttler, A.Met., A.I.M.—Works Manager with Messrs. C. G. Carlisle and Co., Ltd., Sheffield. Mr. Buttler was educated at High Storrs Grammar School, Sheffield, and started work in the steel foundry of the English Steel Corporation, but left to take a course in metallurgy at Sheffield University. In 1946, after five years in the R.A.F., he rejoined the English Steel Corporation and continued at Sheffield University, being awarded the A.Met. in 1948. In that year he joined the staff of the British Iron and Steel Research Association as research metallurgist in the Steelmaking Division. He took up his present position in 1951.

J. W. Grant, A.M.I.Mech.E.—Senior Research Officer at the British Cast Iron Research Association. Mr. Grant joined the Association as a laboratory apprentice in 1938 and as part of his training he spent a period in the foundry and works of Revo Foundry, Ltd. He has been engaged in research on the mechanical properties and engineering aspects of cast irons in general, and has contributed to the development of nodular cast irons.

THE IRON AND STEEL ENGINEERS GROUP

The **Sixteenth Meeting** of the Iron and Steel Engineers Group will be held at 4 Grosvenor Gardens, London, S.W.1, on **Tuesday, 4th December, 1951.**

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Enlarged London Laboratories

The Association have acquired the whole of the light industrial premises at 140 Battersea Park Road, London, of which their Physics, Chemistry, and Plant Engineering Laboratories now occupy about one quarter. This will make available some 43,000 sq. ft. of additional laboratory and office accommodation, until recently occupied by the research department of Powell, Duffryn Research Laboratories, Ltd.

The Plant Engineering Division and Chemistry Department, including the Corrosion and Refractories Sections, will move into the new accommodation as soon as necessary alterations have been completed. This will also make possible an expansion of the Physics Laboratories.

36th Steelmaking Conference

This was held at Ashorne Hill on 2nd and 3rd May and was attended by almost 150 members. The subject was the all-basic open-hearth furnace and papers were read which dealt with various aspects of the furnace and its materials of construction. An impromptu contribution was made by a delegate of the Royal Dutch Steelworks at Ijmuiden who gave up-to-date information on the two all-basic trial furnaces at that works.

During the vigorous discussion that followed it appeared that with a little more development the all-basic furnace could be justified economically.

NEWS OF SCIENCE AND INDUSTRY

Conference on Mixing and Agitation in Liquid Media

The Institution of Chemical Engineers is holding a Conference on mixing and agitation in liquid media at the Royal Institution, on Tuesday, 17th July, 1951, at 10.0 A.M. Further information may be obtained from the Honorary Secretary, The Institution of Chemical Engineers, 56 Victoria Street, London, S.W.1.

Discussion on Heat Transfer

A Conference on the developments in the mechanism of transference of heat and in the design of apparatus relating thereto is being arranged jointly by the Institution of Mechanical Engineers and the American Society of Mechanical Engineers (as announced in the January, 1951, issue of the *Journal*). It will take place from Tuesday to Thursday, 11th–13th September, 1951, and will be held simultaneously in Caxton Hall, Caxton Street, London, S.W.1, and in the Institution of Mechanical Engineers, Storey's Gate, London, S.W.1.

The papers, which will be restricted to developments during the last ten years, will be presented at the Conference in abstract; preprints will be available. The papers and discussion will be published in a bound volume after the Conference. A registration fee (half fee for ladies) will be charged. A James Clayton Lecture will be delivered on the Wednesday evening.

Fifty-two Societies in Great Britain and the Commonwealth, in Europe, and in the U.S.A. are collaborating with the organizing Institutions, and attendance is limited to members of these collaborating bodies. Members of The Iron and Steel Institute wishing to attend, should apply to the Secretary of The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1, for a preliminary reply form.

International Foundry Congress

An International Foundry Congress, organized by the Association Technique de Fonderie de Belgique, will be

held from 10th to 14th September, 1951, in the Fabrimetal building, 21 rue des Drapiers, Brussels.

The subjects to be discussed will include : New cast-iron structures ; testing methods of cast iron and alloys ; light alloys ; the foundryman's daily problems and their influence on productivity ; foundry education.

Further particulars may be obtained from the General Secretary of the Congress, c/o Fabrimetal, 21 rue des Drapiers, Brussels.

Iron and Steel Productivity Scheme

With Sir Charles Goodeve as Leader, the Iron and Steel Productivity Team of the British Iron and Steel Federation left England on 17th May to visit the U.S.A. As one of the teams organized by the Anglo-American Council on Productivity, its objects are :

(1) To study and report on the organization and methods of the U.S. Iron and Steel Industry in the production of steelmaking pig iron, open-hearth steel, and heavy rolled products (heavy bars and sections, rails, plates, and billets)

(2) To consider those factors relevant to the comparative productivity of the U.S. and U.K. industries in the above sections, and to draw conclusions accordingly

(3) To recommend how far and by what methods the principles and experience of the U.S. industry can with benefit be applied or adapted to the U.K.

Société des Ingénieurs Civil de France

M. GEORGE VILLE, Ingénieur des Arts et Manufactures, has been appointed Délégué Général of the Société des Ingénieurs Civils de France.

Institution of Mining and Metallurgy

The Council of the Institution of Mining and Metallurgy announce the following awards :

Honorary Membership—Conferred on Sir HENRY TIZARD, G.C.B., A.F.C., F.R.S., in recognition of his outstanding services to science, industry and education, and on Sir ANDREW BRYAN, J.P., H.M. Chief Inspector of Mines, in recognition of his distinguished services to the mining industry of the U.K.

Gold Medal of the Consolidated Gold Fields of South Africa, Ltd.—Conjointly to J. P. NORRIE, B.Sc., and W. T. PETTIJOHN, for a paper on " An Outline of Underground Operations at Mufuliera Copper Mines, Ltd."

Forty Guinea Premium of the Consolidated Gold Fields of South Africa, Ltd.—Conjointly to H. L. TALBOT, and H. N. HEPKER, B.Sc., for a paper on " Investigations on the Production of Electrolytic Cobalt from a Copper–Cobalt Flotation Concentrate."

William Frecheville Students' Prize—To G. J. MORTIMER, M.B.E., for a paper on " Grade Control."

Beilby Memorial Awards, 1950

The Administrators of the Sir George Beilby Memorial Fund, representing the Institute of Metals, the Royal Institute of Chemistry, and the Society of Chemical Industry, have decided to make two awards, each of one hundred guineas, from the Fund for 1950. These awards have been made to :

WILLIAM ALBERT BAKER, B.Sc.(Lond.), F.I.M., in recognition of his experimental contributions to knowledge of the factors determining the production of sound castings of non-ferrous metals and alloys.

GORDON WHITTINGHAM, M.A., Ph.D.(Cantab.), in recognition of his experimental contributions to knowledge of the combustion products of fuels containing sulphur and their effects on corrosion.

Awards from the Fund are made to British investigators in science as a mark of appreciation of distinguished work, particularly in such fields as fuel economy, chemical engineering, and metallurgy in which Sir George Beilby's special interests lay. In general, the awards are not applicable to the more senior investigators but are granted as an encouragement to relatively young men who have done independent work of exceptional merit over a period of years.

National Physical Laboratory

" N.P.L." by John Langdon Davies, the Jubilee Book of the National Physical Laboratory, has been published by H.M. Stationery Office (price 4*s*.).

The N.P.L. completed its first fifty years on 1st January, 1950, but the Lord President of the Council directed that the Jubilee should be celebrated during the Festival of Britain. During Open Days from 23rd–29th May, 1951, representatives of Universities, Government Departments, and industrial organizations had the opportunity of visiting the Laboratories to see exhibits and demonstrations of the wide variety of work undertaken by the N.P.L.

The National Physical Laboratory was the second of the great national research laboratories to be founded. The first was the Physikalisch-Technische Reichsanstalt in Germany. Two years after the N.P.L., the National Bureau of Standards of the U.S.A. was founded.

The Jubilee Book, which contains 168 photographic illustrations, describes the origin of the Laboratory, its organization and its work, ranging from the maintenance of standards to projects of long-term research.

Changes of Address and Title

FERROMET (LONDON) LTD., has changed its name to Henry C. Bull (London) Ltd. The office remains at 66 Victoria Street, London, S.W.1 (Tel. : Victoria 6565-6-7).

THE UNITED STATES STEEL COMPANY. The H. C. Frick Coke Company, The United States Steel Corporation of Delaware, and the Carnegie-Illinois Steel Corporation have been consolidated and will continue as The United States Steel Company.

DIARY

14th–21st July—INTERNATIONAL WELDING CONGRESS—Institution of Civil Engineers, Great George Street, London, S.W.1.

16th–21st July—DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH—Conference on Automatic Control—London.

17th July—INSTITUTION OF CHEMICAL ENGINEERS—Conference on Mixing and Agitation in Liquid Media—The Royal Institution, 21 Albemarle Street, London, W.1, 10 A.M.

TRANSLATION SERVICE

(The previous announcement was made in the June, 1951, issue of the *Journal*, p. 184).

TRANSLATION IN COURSE OF PREPARATION

(French). J. CYTHER and A. DENYS : " Note on the Operation on Run-of-Mine Ore of a Large French Blast-Furnace with a Hearth 6·50 metres in Diameter." (*Revue de Métallurgie, Mémoires*, 1951, vol. 48, Feb., pp. 73–84).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

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MINERAL RESOURCES

Classification and Description of the Asturian Oolitic Ores. P. Hernandez Sampelayo. (Instituto del Hierro y del Acero, 1950, vol. 3, Apr.–June, pp. 111–115). [In Spanish]. The author proposes five divisions in the classification of the ferruginous paleozoic ores of Asturias. Geographical outline and geological details of each division are given.—R. S.

Report on the Southern Zone of the Iron Ore Deposits of Vizcaya. (Instituto del Hierro y del Acero, 1950, vol. 3, July–Sept., pp. 226–233). [In Spanish]. Work was carried out to confirm, by drilling, the assumptions from earlier surface studies and to obtain a better idea of the origins of the iron ore deposits in the Vizcaya–Santander region. The stratigraphy and main tectonic elements, as previously found by Rios, are described and details of further discovery of a system of faults and eruptive dykes in that region are given. Present drillings show that the average depth of this ore-bearing carbonate had been underestimated. Reserves of 15 million tons are estimated for this zone, of which 15% are rich Rubio and 85% carbonates.—R. S.

Results of Manganese Explorations in Amapá. (Mineração e Metalurgica, 1950, vol. 15, Sept.–Oct., p. 92). [In Portuguese]. This is a note of a survey report put before the Brazilian National Council of Mines and Metallurgy, describing the state of research into the manganese deposits of Amapá. Drillings have been made in the greater part of three of the 28 known deposits and these indicate a total of three to four million tons for the entire Chumbo reserves. Details of estimates for other manganese reserves are given.—R. S.

ORES—MINING AND TREATMENT

Australian Iron Ore : Broken Hill Subsidiary's Cockatoo Island Project. G. Taylor. (Iron and Steel, 1950, vol. 23, Apr., pp. 131–132). The author discusses the preparations being made by the Australian Iron & Steel Ltd. (a subsidiary of the Broken Hill Proprietary Co., Ltd.) to win 25 million tons of hematite iron ore at a rate of a million tons a year from the deposits on Cockatoo Island, and indicates the difficulties which have to be overcome.—G. F.

Preliminary Results of Ore Preparation at the Damme Mine. G. Sengfelder. (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 957–958). The favourable structure and chemical composition of the ore at this mine make a simple wet mechanical method of preparation possible. The process and the recovery of water from sludge by adjustment of *p*H are described.

New Results in the Operation of the Lime Sintering Process. H. Boos. (Stahl und Eisen, 1950, vol. 70, Nov. 23, pp. 1108–1111). From previous investigations, it is known that bonding of the lime in sintering affords marked advantages for the operation of the sintering process and the blast-furnace. The results of tests show that to avoid transport difficulties, it is convenient to add the necessary lime on the sinter belt itself. Comparative tests with different lime additions to the sinter mix have shown that 4% of lime is the optimum for belt output and properties of the sinter. A further increase in output was obtained by increasing the suction. An increased blast-furnace through-put of some 15% with a coke saving of 10% is to be expected with such material. An additional advantage of the process is a marked reduction in sintering costs.—J. P.

FUEL—PREPARATION, PROPERTIES, AND USES

West European Co-operation in Research on Flame Radiation. (Metalen, 1950, vol. 4, June, pp. 218–219). [In Dutch]. This is a brief note on the French–British–Dutch co-operative research on flame radiation and heat transfer. The Royal Dutch Steelworks at Ijmuiden built a special furnace in 1947–48. No technical details are given.—R. S.

Operation and Equipment of Coal-Fired Industrial Furnaces. H. Wübbenhorst. (Brennstoff, Wärme, Kraft, 1950, vol. 2, Sept., pp. 269–271). The author considers fuel utilization and instrumental control in solid-fuel-fired furnaces to be below the standard achieved in gas-fired or electric furnaces. In discussing measures of improvement he briefly describes and discusses various methods of firing, and new equipment developed mainly in British practices, *e.g.*, correct air control, waste-gas heat regeneration, moving grates, mechanical stokers, and down-jet firing.—E. C.

Graphical Calculation of the Heat Transfer with Forced Flow in Pipes. H. Keller. (Von Roll Mitteilungen, 1950, June, pp. 38–47). To simplify the determination of the heat-transfer coefficient for the flow inside pipes, nomograms, based on the usual heat-transfer coefficients, are presented. The formulæ employed have the same form for all flow conditions, and the physical properties of the fluid at its mean temperature are generally inserted. The results of recent research enabled the relationship between the heat-transfer coefficient for the turbulent region to be determined.

E. C. S.

Theory of Heat Transfer. (Engineering and Boiler House Review, 1950, vol. 65, May, pp. 140–143 ; June, pp. 174–178 ; July, pp. 208–212 ; Aug., pp. 244–248 ; Sept., pp. 278–280 ; Oct., pp. 310–313 ; Nov., pp. 340–343 ; Dec., pp. 374–377). Part I is historical. Part II deals with theories of conduction, convection, and radiation. Part III and the last section of Part II discuss heat transfer through the wall of a hollow cylinder. Part IV deals with heat transfer through the wall of a hollow sphere and with convection heat transfer through extended surfaces. The fundamental laws of radiant emission are considered in Part V, and Part VI treats problems of radiant heat transfer between solid surfaces. The penultimate instalment deals with radiation from gases at high temperature to heat-absorbing surfaces, and the concluding instalment summarizes the concepts upon which the analytical approach to problems of forced convection are based and gives simplified data for the solution of convection problems in boiler engineering practice.—E. C. S.

Some Means of Surplus Heat Recovery and Utilization. W. A. Johnson. (Proceedings of the Institution of Mechanical Engineers, 1950, vol. 162, No. 2, pp. 205–208). The degree to which waste heat can be recovered from coke ovens, blast-furnaces, open-hearth furnaces, reheating furnaces, and finished steel after rolling is considered and brief descriptions are given of metallic recuperators, including the Escher recuperator. Curves show the fuel saving due to air preheat for coke-oven gas and the recuperator heating surface required for various air preheats. A comparison between regenerators and recuperators is made. Finally, boilers and gas turbines for utilizing waste heat in a steelworks are discussed.—R. A. R.

The Preparation of Coal. F. W. Mayer. (Brennstoff, Wärme, Kraft, 1950, vol. 2, July, pp. 187–193). After an elementary introduction of the method of sink-float analysis, brief definitions are given of physical processes which underlie methods of coal preparation, *viz.*, elutriation, heavy media, sedimentation, froth flotation, electrical resistivity, and electrostatic processes. Technical methods of beneficiation and equipment are explained in principle and illustrated by simplified flow sheets. Included are Harz jigs, heavy-media processes, and a simplified circuit for a Driessen cone washer. Cyclone thickeners are dealt with, also log washers and pneumatic sedimentation. A complete but simplified jigging circuit and flow scheme are explained. The author considers the technical development of coal preparation as being essentially completed, present work aiming at improvement and refinement of existing methods.—E. C.

Coal Blending for Carbonisation in Coke Ovens. (British Coke Research Association, Technical Paper No. 4, Oct., 1950). This paper describes the practical aspects of blending coal as applied to coke-oven operation in the United Kingdom. The importance of the subject, both economically and as a means of assisting coal conservation, is demonstrated, and means are considered by which materials other than coking coal may be added to the blend in order to produce coke suitable for metallurgical purposes. An account is given of a survey of British coking plants, and blending equipment is considered in the light of the information acquired. Recommendations are made for the design of coal-blending plant. Methods are discussed for determining the suitability of coals for carbonization and for establishing the most satisfactory proportions in a blend to produce coke for a specified purpose. The routine checking of the performance of blending plant is also examined. The practical problems involved in blending are reviewed, and the possibilities are considered of adding to the blend materials other than coking coal. The use of anthracite fines, coal tar pitch, coke breeze, and flue dust is discussed. A method is presented for the calculation of the economic effects, resulting from the introduction of breeze blending, upon the operational cost of a plant.—P. C. P.

Classification of Properties of Coke Characterizing Its Behaviour in the Blast-Furnace Process. K. I. Syskov. (Izvestiya Akademii Nauk S.S.S.R., Otdelenie Teknicheskikh Nauk, 1949, No. 4, pp. 514–518). The properties of blast-furnace coke are considered and classified in three groups which are characterized by their effects on blast-furnace performance, smoothness of descent of the burden, and fuel consumption, respectively. The specific properties in each group are defined.—R. A. R.

Fuel Oil As an Absorbent in Recovery of Light Oil. C. R. Montgomery. (Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 74–78). In the U.S.A. the recovery of light oil from coke-oven gas is usually done by absorption with a higher boiling-point petroleum oil. The light oils absorbed or 'washed' from the gas are then recovered from the wash oil by distillation. This paper describes a series of exploratory tests carried out by the By-Product Coke Department of the Pittsburgh Steel Co. on possible substitutes for the usual rather high-priced absorbent oil. The author examines the following properties: Pour point, absorptive capacity, tendency to emulsify, chemical nature (paraffinic or naphthenic), and tendency to form gums or sludge, all of which are guides in the selection of a good wash oil. The author concludes that the cheaper wash oil used is satisfactory and that the recovery of light oil has not suffered, that the system has remained clean, that the products have retained their high quality, and that the company are saving 4·5 cents per gallon of wash oil.—M. D. J. B.

The Effect of Varying the Depth of Fuel Bed in Gas Producers. T. J. Brzozowski, S. A. Burke, and G. A. Sparham. (Journal of the Institute of Fuel, 1950, vol. 23, Sept., pp. 255–262). Tests were made with the object of determining the effect of fuel-bed depth on gas composition and its influence on the gas off-take temperature in a mechanized producer in the absence of water-cooled surfaces. All the tests were carried out on a non-caking coal of uniform type and size-grading, and at constant blast saturation temperature. Investigations were carried out on an International Furnace Equipment producer over a range of bed depths from 14 to 54 in. The results showed that over a certain range of depth the composition and calorific value of the gas were profoundly influenced. The gas quality fell off sharply for bed depths below a critical value of 25 in. Among the practical conclusions drawn are the need to increase the bed depth in hot raw gas producers when conditions permit, the value of automatic control of coal feed, and gas off-take temperature, certain disadvantages of water-cooled surfaces in a hot raw gas producer, and further support for insulation of gas mains.—J. P. S.

REFRACTORY MATERIALS

Basic Refractories. Their Chemistry in Relation to Their Performance. J. R. Rait. (Iron and Steel, 1949, vol. 22, May 12, pp. 187–193 ; June, pp. 289–293 ; Nov., pp. 493–498 ; Dec., pp. 623–628, 640 ; 1950, vol. 23, Jan., pp. 15–19 ; Mar., pp. 88–92 ; May 11, pp. 183–189). A review of the compositions of typical basic refractories including dolomites, dolomite magnesites, sea-water magnesites, magnesites, and forsterites reported in the literature shows that these are composed essentially of CaO, MgO, SiO_2, Al_2O_3, and Fe_2O_3. A knowledge of that portion of the five-component system $CaO–MgO–SiO_2–Al_2O_3–Fe_2O_3$ in which periclase occurs as one of the phases is essential for the determination of their constitutions. As all the data required on appropriate oxide systems are not available, the additional data required have been determined and the phase groupings for the portion of the five-component system in which periclase is one of the phases have been established by X-ray powder and petrological examination of many sinters. The constitutions of a large number of typical dolomites and magnesites from various sources have been calculated from the data on phase groupings, and verified by the X-ray powder method and petrological investigations. Typical X-ray photographs and thin sections are reproduced. The constitutions of chrome ores have been investigated and a method developed by which not only the constitution of the chrome spinel grains, but also the constitution of the matrix and the amounts of chrome spinel and matrix, can be determined. The thermal equilibrium diagrams of smaller systems within the major five-component system have been investigated. The temperatures of initial formation of liquid and the amounts of liquid formed at various temperatures in mixes within these systems have been calculated and tabulated. With these data, contents of liquid can be accurately determined for certain basic refractories, and, for the others, temperatures of initial liquid formation and amounts of liquid at various temperatures can be approximately estimated. When CaO is present, liquid may be formed in basic refractories at low temperatures in the region of 1260° C. but in the absence of CaO, liquid is not formed below 1580° C. Liquids formed in basic refractories, in contrast to the siliceous refractories, are extremely fluid, so that the temperatures at which liquid is first formed and the amounts of liquid formed at the higher temperatures

have a major influence on such high-temperature properties as refractoriness-under-load. The correlation between liquid contents and refractoriness-under-load of typical dolomites, magnesites, and chrome-magnesites is satisfactory. The performances of basic refractories under various service conditions, particularly in basic open-hearth roofs and basic electric steel furnace linings, have been investigated; the mode of destruction and methods for improving the performance have been described.

Assessing Open-Hearth Furnace Roof Bricks by Roof Temperature Measurement. K. G. Speith and G. Engels. (Stahl und Eisen, 1950, vol. 70, Sept. 28, pp. 861–867). A review of results from specification tests conducted over a period of ten years has indicated that they do not give satisfactory information about the performance of bricks. Their quality could be assessed by a determination of the roof temperature at which the bricks begin to drip. Within experimental accuracy, the dripping point did not change during the course of a campaign; this was unexpected. It is possible to record temperatures during a campaign and so obtain useful information to correlate with roof performance. Output and melting programme must, of course, be taken into account. It has been established that a roof temperature recorder can ease the task of furnace supervision.—J. P.

A Proposed Method of Test for Specific Heat of Thermal Insulating Materials. N. H. Spear. (Bulletin of American Society for Testing Materials, 1950, Sept., pp. 79–82). The paper describes an apparatus and procedure under consideration for standardizing the determination of the mean specific heat of thermally insulating material. The method is a simple application of the 'method of mixtures' in which a metal capsule containing the material in question is dropped from a furnace into a Dewar vessel containing a known quantity of calorimetric fluid and the temperature change of the latter is measured with a mercury in glass thermometer. Calibration is performed by filling the capsule with a known amount of a substance whose mean specific heat in the same range is known. Comparison is made of results obtained with several apparatus of this type.—J. J.

Anomalous Viscosities in the MnO–SiO_2 System. H. Towers and J. Kay. (Transactions of the British Ceramic Society, 1950, vol. 49, Aug., pp. 341–356). Viscosity measurements were made on slags in the MnO–SiO_2 system, and the apparatus used is described. Slags in which the molar ratio $SiO_2/MnO = 1{\cdot}0$ or greater possess anomalous viscosities in that apparent viscosity decreases with increases in the rate of shear. Goodeve's contribution to the theoretical study of viscosity is cited and a qualitative mathematical hypothesis is offered as an explanation of the anomaly and related to dissociation of silicate structures in the liquid state.—E. J. D. S.

The Spalling Resistance of Magnesite Products. Part III. The Effect of Iron Oxide Additions. W. F. Ford and W. J. Rees. (Transactions of the British Ceramic Society, 1950, vol. 49, Sept., pp. 375–385). Many factors influencing the spalling resistance of sea-water magnesites were found during the investigations; some are briefly discussed and an attempt to correlate the shape of spalling-resistance/composition curves with variations in crystal size and composition of the bond is reported. Maximum spalling resistance occurred at about 3% iron oxide. Higher oxide contents than this produced a lowering of thermal spalling resistance. Curves of apparent porosity showed a minimum which coincided approximately with the 3% iron oxide content. However, a greater improvement in spalling resistance was observed when the iron oxide was added to the magnesite during dead-burning than when added to the brick batch.—E. J. D. S.

Developments in Refractory Materials. (Metallurgia, 1950, vol. 42, Aug., pp. 119–122). A review is made of recent developments in manufacturing methods and products of the British refractory materials industry. Examples are given of new plant for manufacturing high-temperature high-alumina bricks; high-temperature insulating bricks with very low thermal conductivities per unit of weight; high-temperature heat-conducting materials of silicon carbide with thermal conductivities ten times as great as firebrick; and new open-hearth lining materials. Special mention is made of carbon refractories and the great benefits enjoyed by all-carbon-lined blast-furnaces.—J. J.

Treatment of Brick to Prevent CO Disintegration. J. A. Shea. (Blast Furnace and Coke Associations of the Eastern States and the Chicago District: Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 116–119). **How to Prevent Blast Furnace Lining Disintegration.** J. A. Shea. (Steel, 1950, vol. 127, Nov. 27, pp. 74, 77, 78). Carbon monoxide disintegration of blast-furnace bricks is briefly described and examples of disintegrated furnace linings are given. The author describes disintegration test equipment developed at the Gary Steel Works and the methods adopted to improve brick life. These include treating bricks with hydrogen chloride gas at elevated temperature, dipping sample bricks susceptible to disintegration in a 10% solution of sulphuric acid, and treating bricks with ammonium sulphate, aluminium sulphate, or hydrogen sulphide. The test results are described in detail. The treatment of bricks with chemical solutions can be accomplished by soaking, dipping, spraying, or by adding the chemical to the bonding material. The effects of heat on bricks are also considered. If only added resistance to disintegration is required this can be obtained at less cost by treating normally fired bricks. Although treatment prevents CO disintegration it should not be regarded as a cure for all lining troubles.

M. D. J. B.

Basic Refractory Products. (Metal Industry, 1950, vol. 77, Nov. 10, pp. 179–183). This article describes the products and methods of manufacture at the Worksop Works of General Refractories, Ltd. The analyses of the main basic raw materials (chrome ore, magnesite, and dolomite), are tabulated, and a list of the products made from them is shown. The brick manufacturing plant, and the chrome ore and magnesite crushing and screening plants, are described and illustrated by diagrams and photographs. The drying, burning, and final testing are briefly described.—P. M. C.

Installation and Repair of a Rammed Lining in a Cupola. (Fonderie, 1949, Dec., pp. 1877–1879). Good monolithic linings for cupolas should contain 6 to 8% alumina (by weight) and have an A.F.A. (American Foundrymen's Association) fineness of about 60. The ramming mass should contain about 20% of coarse silica (1·5 to 5 mm.) and a minimum of fine dust. Maximum contents of impurities in the clay bond should be 0·20% magnesia, 0·80% lime, 0·50% alkaline oxides, and 1·00% iron oxide. Detailed instructions for the preparation of the mass are given. Laying on operations, using a form or core, and drying instructions are given. Some notes are added on a mixture for repairs and method of its application.—R. S.

How to Choose Blast-Furnace Refractories. R. P. Heuer and C. E. Grigsby. (Steel, 1950, vol. 127, Sept. 4, pp. 99–104; Sept. 11, pp. 100–105; Sept. 18, pp. 126–134). The authors discuss the factors causing the breakdown of refractories under operating conditions. Failure of hearth is usually due to ferrostatic pressure and reduction of silica in the brick; the lower half of the stack is subject to carbon disintegration and slag and alkali attack, and the upper half is subject to carbon disintegration and physical abrasion. The use of sillimanite is suggested for resistance to carbon disintegration and slag and alkali attack. A short description is also given of experiments with carbon linings, and failures are attributed to bad design and inadequate thickness. The conditions under which linings have to operate in hot blast mains and stoves are discussed.—A. M. F.

Blast Furnaces Operate with All Carbon Lining. G. D. Elliot. (Iron Age, 1950, vol. 166, Sept. 21, pp. 88–91). The experimental work with carbon linings at the Appleby-Frodingham Steel Co., Ltd., is described. The benefits gained should be more than sufficient to offset the increased cost and these benefits are stated to be: Increased campaign life, simplified construction, elimination of stack cooling, simpler and cheaper hearth cooling, less chance of formation of scabs and scaffolds, and reduced lining requirements. It has also been shown that rapid heating of the carbon brick is harmless and that after five months of operation the wear on the lining was practically nil, and it had remained hard and clean.

A. M. F.

Properties of Available Blast-Furnace Refractories. M. A. Fay. (Iron and Steel Engineer, 1950, vol. 27, Oct., pp. 55–59.) The chief causes of failures in blast-furnace linings are reviewed. Carbon disintegration, the result of precipitation and deposition of carbon from carbon monoxide in the interior of refractory bricks, is discussed as well as chemical attack first by alkali vapours in the furnace gases and by liquid furnace slag. The author shows how high-alumina

refractories with low porosity and low permeability tend to restrict the penetration of fluxing agents. The lack of volume stability, characteristic of many porous refractories when heated to high temperatures, is examined as well as the damage done to furnace linings by abrasion from falling stock. The simultaneous effects of all these factors affecting the life of the linings are considered in the light of modern practice and developments in the manufacture of fireclay refractories. The use of high alumina, sillimanite bricks is suggested and the advantages of sillimanite mortar for laying up hearth and bosh sections are described.—M. D. J. B.

A Progress Report on Carbon in Blast Furnaces. E. J. Ess. (Iron and Steel Engineer, 1950, vol. 27, Nov., pp. 68–75). This paper describes the progress which the carbon hearth has made in the U.S.A. during the last few years. Details are given of German and especially English practice where the carbon lining has met with more favour than in America. Considerable information is given on English experience, especially Appleby-Frodingham practice, and reference is made to a number of G. D. Elliot's papers. Statistical information on American carbon-lined blast-furnaces is given together with constructional details, principal dimensions, and operating conditions. The author suggests that one should have an open mind about carbon as a furnace refractory, and that only time and experience will show whether the high virtues of carbon, claimed by some, are justified.

M. D. J. B.

Radioactive Indicators for Blast-Furnace Refractory Wear. E. W. Voice. (Journal of The Iron and Steel Institute, 1951, vol. 167, Feb., pp. 157–161). Some isotopes emit strongly penetrating gamma radiations which can be detected through two or three feet of firebrick. This property may be used to give evidence of blast-furnace refractory wear, and details of the method are given.

The Preparation of Rammed Linings from Dolomite of High Packing Density. G. Trömel. (Stahl und Eisen, 1950, vol. 70, Sept. 28, pp. 883–887). Experience with rammed linings from graded dolomite for open-hearth and electric furnaces and converters, as reported in the Iron and Steel Institute Special Reports Nos. 33 and 35, are reviewed. The questions dealt with are the methods of preparation of linings, and bricks, reactions between linings, slags and steel, and patching.—J. P.

Wear of Open-Hearth Silica Roof Bricks, Having the Same Appearance but Different Causes. R. Frerich. (Stahl und Eisen, 1950, vol. 70, Sept. 28, pp. 870–873). Three examples are illustrated, in which the faces of silica roof-ribs are corroded more than those of adjacent shorter bricks. In the first instance, this can be attributed to the inferior quality of the rib bricks (high Al_2O_3 + TiO_2 content). In the others, the bricks were all of one quality and the damage must be ascribed to the fact that heat flow from the face of a long brick is less rapid than from that of a short brick, resulting in a higher face temperature and faster slagging by dust, etc. It is suggested that in ribbed roof construction, care should be taken to ensure that heat flow is made uniform. Some observations are made about the care necessary in compounding silica mortar to avoid excess alumina additions.

J. P.

Roof Performance of Open-Hearth Furnaces during the Years 1937 to 1949. W. Baumgardt. (Stahl und Eisen, 1950, vol. 70, Sept. 28, pp. 867–869). Results from 30 and 60-ton furnaces show that during the years 1937–42 there was a progressive deterioration in the life of silica roofs, attributable to the exigencies of war and raw-material supply difficulties. Fortunately, during 1948 and 1949, manufacturers of refractories have been able to overcome some of these and the life of silica bricks for open-hearth roofs is now as good as that in 1937, though the advent of ribbed and stressed roof construction is partly responsible for this. A new warming-up programme has been laid down so as to avoid damage from too rapid thermal expansion.—J. P.

Construction and Maintenance of Open-Hearth Furnace Bottoms. C. W. Conn. (Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 100–102). The development of basic open-hearth furnace bottoms is reviewed. When Austrian magnesite became limited after 1914, chromium brick was used. Later, and up till 1929, magnesite mixes were rammed in and chrome ore mixes applied, until a plastic chrome hearth refractory was developed for this purpose. In 1939, cold-ramming high-magnesia refractory was introduced as a unique material for new hearth construction and for major repairs to bottoms and banks. The author describes a variety of ramming practices and materials and mentions exhaustive studies which have been made to determine the relative merits of various ramming materials and to establish whether the fully rammed, partially rammed, or fully burned-in bottom is best. The comments of the National Open Hearth Committee for 1945 on open-hearth bottom construction and materials are briefly referred to. The causes and nature of furnace bottom troubles are discussed and it is suggested that much of the trouble is created by the human element and, in order to offset this, a scheme of apprenticing first helpers is offered.—M. D. J. B.

A Mineralogical Study of the Corrosion of Checker Bricks from Open-Hearth Steel Furnaces. Liang-Ho Su. (Transactions of the British Ceramic Society, 1950, vol. 49, Oct., pp. 420–453). Samples of 42% alumina, silica, and semi-silica bricks, from open-hearth regenerator checkers were examined in detail. Samples of the first type were from the top courses of an air checker and samples of the other types were from both gas and air checkers. Thin-section mineralogical technique was used to determine the crystalline phases and glasses encountered between the slagged surfaces of the bricks and their cores. Among the phases identified and discussed was the garnet andradite found in the corroded silica brick from the top course of the gas checker. This and other separated samples consisting of spinels or spinel solid solutions were studied by X-ray diffraction. It is suggested that the general characteristics of the products of reaction between slag and brick can be inferred from the results of the investigation. The corroding slag is composed of various oxides of which the main ones are lime and iron oxide. Lime forms calcium alumino-silicates with alumina bricks and calcium meta-silicates by reaction with silica bricks. Oxides such as MgO, MnO, ZnO, and Cr_2O_3 tend to form spinels complicated by the presence of iron oxides. The process of corrosion of refractories by slags is discussed.

E. J. D. S.

TEMPERATURE MEASUREMENT AND CONTROL

Open Hearth Bath Pyrometers. H. B. Emerick. (Blast Furnace and Steel Plant, 1950, vol. 38, Dec., pp. 1425–1427). The author discusses the advent of practical open-hearth bath pyrometers as a scientific tool to supplement the individual melter's skill in the art of temperature control. The importance of temperature control is stressed in relation to quality of product and economy of operation.—J. P. S.

Electric Controllers for Laboratory Furnaces. M. H. Roberts. (Electronic Engineering, 1951, vol. 23, Feb., pp. 51–54). Two designs of temperature controller for laboratory electric resistance furnaces are described. The general design is based on previous circuits used by Prosser, Coates, and Yates, but more emphasis is laid upon simplicity of construction and operation, economy, use of only standard components, and design for maximum expectation of life and minimum probability of breakdown, the most likely failures being arranged to send the furnace temperature down, not up. The first design gives simple two-position control, and is adequate for general metallurgical heat-treatment, while the second design, used in conjunction with a saturatable inductor, gives proportional control by smooth variation of power from maximum to nearly zero, and is superior where available voltages, and thermal lag due to furnace arrangement, make the oscillation with two-position control greater than is permissible.—E. T. T.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

The Clyde Iron Works of Colvilles, Limited. R. P. Towndrow. (Iron and Coal Trades Review, 1950, vol. 161, Sept. 22, pp. 462–465, 469). The Clyde Iron Works of Colvilles, Ltd., is described, special attention being given to the handling of raw materials, the coking and by-product plant, ore preparation and handling, and the blast-furnaces and auxiliary plant. The steam-raising plant, works' supplies of electricity and water, and internal transport are also briefly described, and recent installations and equipment are indicated.—G. F.

The Introduction at Donawitz of Twin Cowper Stove Operation without the Use of Special Bricks. A. Vacek. (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 1014–1015). The conversion, at the Österreichische-Alpinen-Montangesellschaft

at Donawitz, from the use of three or four stoves per blast-furnace to the use of two improved stoves is described. These stoves, which have wide checkering in their upper, and narrow checkering in their lower portions, when operated with cleaned gas and forced draught, have shown themselves to be more efficient than those used formerly and do not require honeycomb or cloverleaf-shaped bricks, conventional rectangular design being satisfactory.—J. P.

Description of the Blast Furnace Controlled Split-Wind Blowing Installation at Algoma Steel Corp., Ltd. W. O. Bishop. (Chicago District Blast Furnace and Coke Association and Eastern States Blast Furnace and Coke Oven Association: Blast Furnace and Steel Plant, 1950, vol. 38, Dec., pp. 1428–1434). A description is given of the layout and controls. The operation of the furnace is discussed.

J. P. S.

Pig-Iron Production by the Humboldt Low-Shaft Smelting Process: Post-War Work in Germany. (Iron and Coal Trades Review, 1950, vol. 161, Dec. 1, pp. 833–834). A brief account is given of the post-war experimental work in Germany to develop a system of low-shaft smelting for fine ores and poor coking coals, the ore, fuel, and flux being pre-mixed and compressed into briquettes. Pilot plant trials showed that with the top of the shaft 4–5 m. above the hearth, the temperature in the upper part of the shaft would be sufficiently low for pre-coking of the briquettes to take place, reduction and smelting occurring in the centre and lower parts. The results obtained on an experimental furnace at Humboldt, equipped with tar-condensing plant, recuperator, and casting bay, have fully justified expectations; the average analysis of the pig iron from 30 casts, using a mixture of copper and aluminium plant residues and an unwashed gas coal of 15% ash content, was: 3·3% C, 2·8% Si, 0·2–1·8% Mn, and 0·03% S. A consideration of costs indicates that the process is likely to be a commercial success.—G. F.

TREATMENT AND USE OF SLAG

Blast-Furnace Slag Building Materials. T. W. Parker. (Institution of Engineers and Shipbuilders in Scotland, 1950, Paper No. 1139, Preprint). A comparison is made of the utilization of slag in this country with that in the United States and Germany. Detailed consideration is given to the constitution and properties of slags when solidified, with special reference to different cooling processes, *e.g.*, rapid quenching in water, foaming processes, and natural air cooling. The various building products using blast-furnace slag, such as cements with alkaline and sulphate exciters, lightweight, foamed slag, and 'no-fines' concrete are discussed, and the effect of factors such as strength, thermal conductivity, moisture movement, rain penetration, and fire resistance, on the utilization of these building materials is described.—P. C. P.

PRODUCTION OF STEEL

Companhia Siderurgiça Belgo-Mineira, Monlevade Works. (Mineração e Metalurgica, 1950, vol. 15, July–Aug., pp. 68–70). [In Portuguese]. These works, in the heart of the Minas Geraes, have four blast-furnaces, four steelmaking furnaces, six rolling mills for blooms, billets, tubes, sheets, and sections, a wire mill, a galvanizing plant, and a foundry. An account is given of the industrial town which has been built up. Output in 1949 was 100,000 tons of steel.—R. S.

Wm. Beardmore and Company, Limited, Parkhead. (Iron and Coal Trades Review, 1950, vol. 161, Sept. 22, p. 455). Brief notes on features of interest at the Parkhead Works of Wm. Beardmore and Co., Ltd., are presented and the different departments of the works are briefly described.

G. F.

The Clyde Alloy Steel Company, Limited, Motherwell: Production of Alloy Steels. D. D. Howat. (Iron and Coal Trades Review, 1950, vol. 161, Sept. 22, pp. 458–461). The Craigneuk Works of the Clyde Alloy Steel Co., Ltd., produces rolled sections, forgings, and steel castings. A substantial proportion of these is made in alloy steel, of special interest being the production of stainless steels, heat-resisting steels, and high-speed steel. Brief descriptions of the electric arc and induction furnaces, the heavy and light steel foundries, the rolling mills, and the heat-treatment shop, are given.

G. F.

The Glengarnock Steel Works of Colvilles, Limited: Melting Shops and Rolling Mills. (Iron and Coal Trades Review, 1950, vol. 161, Sept. 22, pp. 466–467). A brief description of the Glengarnock Steel Works of Colvilles, Ltd., is given. The main features dealt with are: The melting shop, which has a capacity of 300,000 tons/annum; the rolling mills, consisting of cogging, billet, and section mills; and the sleeper and fishplate plant, which regularly makes 900–1000 tons of sleepers per week. A brief history of the works is included.—G. F.

Blowing Basic Steel Converters with Oxygen-Enriched Air. Experiences at the Eisenwerk-Gesellschaft Maximilianshütte, Sulzbach-Rosenberg (Hütte). B. Richthof. (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 959–961). The plant for preparing oxygen-enriched air and feeding it to the converters is described. The feed lines incorporate quick-action valves which enable the blast to be changed rapidly from normal to oxygenated air and *vice versa*. These can be used to prevent the loss of iron by burning at too high temperatures, as well as to prepare steel with nitrogen contents of 0·008–0·012% by cutting off the oxygen at the correct time. The advantages gained from oxygen enrichment are: (1) Reduction of blowing period; (2) increase in scrap charged; (3) ability to blow high-phosphorus irons; and (4) increased solubility of the slag in citric acid.—J. P.

Production of Low-Nitrogen Basic-Bessemer Steel by the Use of Oxygen-Enriched Air. T. Kootz and W. Oelsen. (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 961–962). The nitrogen content of finished steel can be reduced as compared with normal practice by additions of ore and lime during blowing, and inclining the converter after the change-over from the carbon to the phosphorus period.—J. P.

Oxygen Blowing of Bessemer Converters. Results of One Year's Trials in the Argentine Republic. E. Masle. (Tecnica e Industria, 1950, vol. 28, Aug., pp. 851–853). [In Spanish]. The author describes trials using oxygen in the acid converters of the Argentinian firm of Repetto and Sforza. Side-blown acid converters were used. Capacity was just under one ton. Blowing pressure was 0·20 atm. through six 1-in. tuyeres. The charge was synthetic cast iron from an adjoining cupola into which were put steel scrap, ingots, ferrosilicon, coke, and limestone. Charges of 100% scrap were also melted. Soda desulphurization was used between cupola and converter. Iron was charged to the converter at 1300° C. Steel was teemed at 1600° C. A blow lasted 11 to 13 min. Oxygen requirements were calculated per ton of iron at 65 cu. m., or 310 cu. m. of air. Actual volume of air blast for the 13 min. was 325 cu. m. With air alone, the first blows lasted 16, 17, and 18 min., producing 'cold' steel. A 1-in. galvanized iron tube was led into the blast main and connected to a trailer containing 28 oxygen bottles. Oxygen pressure was reduced to 7 atm. to flow into the air main at 120 cu. m./hr. and at a pressure of less than 1 atm.

Flexible use of oxygen guarantees a uniform heat, and there is no need to feed ferrosilicon to the converter. The same deoxidizing additions can be made to the ladle. Uniformity of analysis and time are obtained. Oxygen can be used for raising the temperature where ferro-alloys have to be added to the ladle. Ten blows can be made in the time previously taken for seven. Consumption of oxygen is 30 to 40 cu. m./ton of steel. There is a considerable reduction in the amount of ladle skulls, and this alone pays the cost of the oxygen. After more than 500 blows with oxygen, this firm is satisfied that oxygen is a useful precision tool for controlling the acid-Bessemer process.—R. S.

Metal Composition Tests for the Steel Melter. H. H. Fairfield, H. F. Graham, and A. E. McMeekin. (American Foundrymen's Society, 1950, May. Preprint, No. 30). The work reported involves a restricted application of Vennerholm's suggestions on the control of medium-carbon steel production. A simplified hardenability test is the main feature of the technique, and, using a cast test bar, the test can be completed in 2 min. by a melter. Under consistent test conditions the tensile strength of acid and basic steel was successfully maintained from heat to heat. The carbon content of steels containing 0·10 to 0·45% C, which are not partially or fully austenitic after quenching, may be determined by this method. The importance of specimen size in the hardness tests is pointed out.—E. J. D. S.

The All-Basic Open Hearth: European and American.

R. P. Heuer and M. A. Fay. (American Institute of Mining and Metallurgical Engineers, 1950, Open Hearth Conference Proceedings, vol. 33, pp. 189–216 : Journal of Metals, 1950, vol. 188, June, pp. 824–829 ; July, pp. 921–928). From an examination of European and American all-basic open-hearth furnace practices, the authors indicate how improvements can be made by consideration of the techniques of producers in both continents. After briefly discussing operating practices, methods of suspending basic roofs are considered in some detail, and European and American basic refractories are compared. Fuel practices are next considered, and direct comparisons between furnaces of various designs are made, indicating that the Maerz type of port end gives superior results.—G. F.

Use of Oxygen Jets through the Back Wall. A. E. Reinhard. (American Institute of Mining and Metallurgical Engineers, 1950 Open Hearth Conference Proceedings, vol. 33, pp. 43–51). **Oxygen Jets through the Open-Hearth Back Wall.** A. E. Reinhard. (Journal of Metals, 1950, vol. 188, June, pp. 835–837). The design and construction of oxygen jets for injecting oxygen into the open-hearth furnace bath at the Great Lakes Steel Corp., Detroit, are described. Each of four 250-ton furnaces is fitted with two retractable water-cooled jets, mounted in water-cooled ports in the back walls and operated from the control panel. The oxygen flow through each jet is 30,000 cu. ft./hr., and the average rate of carbon removal, starting at 0·30–0·40% and reducing to 0·08%, is 0·010%/min. with two jets and 0·0065%/min. with one jet. Rapid conditioning of the slag is obtained, and the position of the jets enables easy and efficient handling without interference with passage of materials across the charging floor. Maintenance is not unduly excessive.—G. F.

Vanadium Treated, Non-Aging, Rimming Steel for Deep Drawing Quality Sheet. S. Epstein, H. J. Cutler, and J. W. Frame. (American Institute of Mining and Metallurgical Engineers, 1950 Open Hearth Conference Proceedings, vol. 33, pp. 153–161 : Journal of Metals, 1950, vol. 188, June, pp. 830–834). Ordinary rimming steel for deep-drawing sheet is prone to age-hardening. It has been replaced to some extent by non-ageing aluminium-killed steel, which has excellent deep-drawing properties but has a poorer surface. The authors describe the production of a none-ageing rimming steel by the addition of vanadium, which fixes the nitrogen but, being a weak deoxidizer, does not prevent the rimming action. The same open-hearth practice as for ordinary rimming steel is used, with a vanadium addition to the ladle of 1 lb./ton (residual vanadium 0·03%). This steel has the good surface of ordinary rimming steel, and tests at room temperature and at 400° F. show that it is as fully non-ageing as aluminium-killed steel, over which it has the following advantages : (1) Better slab yield ; (2) less surface conditioning ; (3) use of a thicker hot band, as a greater cold reduction is possible ; and (4) fewer rejections for poor surface. The cost of the vanadium addition, however, necessitates using the product of the whole ingot, and in this connection data concerning the properties of sheets from the top and bottom ingot cuts are given. Little variation in composition is shown, and even in very severe deep-drawing, the performance of sheets from the top cuts is satisfactory.—G. F.

A Method of Nozzle Setting. W. G. McDonough. (American Institute of Mining and Metallurgical Engineers, 1950 Open Hearth Conference Proceedings, vol. 33, pp. 81–87). **Setting Ladle Nozzles.** W. G. McDonough. (Journal of Metals, 1950, vol. 188, June, pp. 838–839). A description is given of the method used at the National Works of National Tube Co. for setting ladle nozzles. A detachable nozzle plate allows removal and replacement of the nozzle from the outside while the lining is still hot, and the time required from finishing pouring one heat to the ladle being ready for the next heat is only 12–15 min.—G. F.

Oxygen in Liquid Open-Hearth Steel : Oxidation during Tapping and Ladle Filling. T. E. Brower, J. W. Bain, and B. M. Larsen. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 851–861 ; Journal of Metals, 1950, June). The authors examine data on the oxidation of the steel stream occurring during tapping, and conclude that the main source of alloy losses during tapping is oxidation by air, the steel apparently reacting with an amount of oxygen equivalent to 20 to 30 times its own volume and at the same time absorbing 0·001–0·002% of nitrogen. The effect varies from heat to heat, being largely dependent on turbulence and distance of free fall of the stream, and is the main variable limiting the degree of control of steel composition. The authors advocate closer control of taphole contour and tapping stream, and decreasing the distance of free fall into the ladle, in this latter connection describing the ' tilting ladle ' method of tapping in which the ladle is initially held practically horizontal and is lowered gradually as tapping proceeds. It is thought that such practices would result in a saving of manganese of 0·4–1·0 lb./ton of steel, with corresponding savings in silicon, aluminium, and other alloys.—G. F.

The Double Slag Melting Process in Basic Lined Electric Furnaces. H. Biers. (Instituto del Hierro y del Acero, 1950, vol. 3, July–Sept., pp. 203–209). [In Spanish]. The process described was for the production of a 4-ton heat of steel for castings. A 6-ton furnace was used. The end analysis was : C 0·25%, Mn 0·60–0·70%, Si 0·40%, P 0·03%, and S 0·03% max. Materials for the oxidizing slag amount to 3–5% of the charge. Slag basicity is 2·5 to 1·0. Analysis of the black oxidizing slag is : CaO 30–45%, SiO_2 8–12%, FeO 12–20%, Al_2O_3 2–3%, MgO 5–10%, Mn 8–12%, P_2O_5 0·5–0·8%, and S 0·1–0·2%. Once the desired carbon content is reached, the oxidizing slag is taken off and, with it, most of the phosphorus and part of the sulphur. After silicon–manganese and the carbon for recarburizing are added to the bath, the pre-mixed refining slag is added. This refining slag contains lime, fluorspar, siliceous sand, and coke to form a calcareous carbide, and has the following range of analysis : CaO 60–65%, SiO_2 18–22%, FeO 0·5–0·7%, Al_2O_3 0·3–0·4%, MgO 7–9%, MnO 0–1%, S 0·3–0·5%, and CaC_2 2–2·5%. Final deoxidation of the steel is effected by adding 18 kg. Ca–Mn–Si in the ladle when the latter is a third full. Melting time is 1¾ to 2¼ hr., oxidizing 30 to 45 min., first slag withdrawal 7 to 10 min., refining 1 to 1¼ hr. Total duration of heat : 3½ to 4½ hr. A complete log is given for a 9-ton heat.—R. S.

Continuous Casting. B. Wollmann. (Tecnica e Industria, 1950, vol. 28, Sept., pp. 971–976). [In Spanish]. Bessemer's continuous casting scheme already possessed all the characteristics of more modern constructions. Some early developments in America and Russia are mentioned and several other types of continuous casting mechanism are described. R. S.

New Ingot Mold Coatings Are in Use. J. J. Golden. (Iron Age, 1951, vol. 167, Mar. 29, pp. 83–85). **New Mold Coatings.** J. J. Golden. (American Institute of Mining and Metallurgical Engineers, 1950 Open Hearth Conference Proceedings, vol. 33, pp. 73–81 ; Journal of Metals, 1950, vol. 188, June, pp. 842–844). Because of the heavy fumes given off when teeming into tar-coated moulds, trials of the mould dressing materials " Darmold " (a colloidal graphite solution) and " Hydropaste " (a non-inflammable paste containing flake aluminium) were made by the Carnegie-Illinois Steel Corp. With respect to steel quality and mould life, both materials compare favourably with tar, and in the specific case of semi-killed steel containing up to 0·30% of carbon, the product from Darmold-coated moulds was definitely superior to that from tarred moulds. Neither material is troublesome from the point of view of fumes. Mould dressing costs in both cases, however, are substantially greater than with tar, and Hydropaste also requires special mixing equipment. A portable tar sprayer and a new type of apparatus designed to apply a very thin coating, are also described.—G. F.

PRODUCTION OF FERRO-ALLOYS

The Manufacture of Ferromanganese. A. Esme. (Métallurgie, 1950, vol. 82, Aug., pp. 611–620 ; Sept., pp. 673–683). The production of commercial ferromanganese in the blast-furnace and the electric furnace is examined. Early methods since 1876 are reviewed. In the manufacture of ferro-manganese in the blast-furnace, the main essentials are : (1) Necessity for reducing manganese losses to the slag ; (2) use of rich ores and low-ash coke to reduce the quantity of slag ; (3) reduction of the amount of slag by maintaining a high basicity ; (4) use of multiple-base slags ; (5) increase in blast temperature and amount of coke reduce slag losses ; (6) waste gas losses vary inversely with slag losses ; (7) optimum conditions of slag basicity, blast temperature, and amount of coke are required to reduce manganese losses ; (8) hot and slow working are required, though the blast

temperature must not exceed 1200° F. or reduction of SiO_2 takes place and the lining is damaged; and (9) ores low in iron must be used to obtain 76 to 80% manganese in the ferro-alloy. Details of burdens for the production of 75–80% ferromanganese and of slag and metal analyses are given. An analysis of manganese losses is made. The cost of electricity affects the relative economy of the blast-furnace and the electric furnace methods but in France the advantages and disadvantages seem to balance and the two methods are in competition. The making of ferromanganese is described. The complex slag problem is discussed and details of a 5-day campaign and of burdens using different ores are given.—R. S.

Dwindling Stocks Spur Manganese Recovery from Slag. R. C. Buehl. (Steel, 1950, vol. 127, Nov. 13, pp. 108–113). The American Bureau of Mines is carrying out work on the reclamation of manganese from open-hearth furnace flush slags to offset the shortage due to accelerated steelmaking activities. The process, which can also be applied to manganiferous iron ore, consists of first reducing the slags containing 9–12% Mn in a blast-furnace. The second part of the process is carried out in a converter where just sufficient air is blown through the metal to produce a high manganese slag. By this method synthetic ferromanganese ores have been produced with a manganese content of 55–63%. Other means of recovery, such as magnetic concentration, leaching, and volatilization are also being tried.—A. M. F.

Production of Ferro-Manganese and Spiegeleisen: Reconstruction of the Mostyn Iron Works. A. R. Parkes. (Iron and Coal Trades Review, 1950, vol. 161, Dec. 1, pp. 803–808). The Mostyn Works of the Darwen and Mostyn Iron Co., Ltd., is engaged solely in the production of ferromanganese and spiegeleisen. Since the war it has been extensively modernized and the blast-furnace now in production has been mechanized. Accounts of the works before modernization and the improvements subsequently effected in layout, capacity, and plant, are presented, special attention being given to coke-screening equipment, scale car and charging gear, gas cleaning plant, and the improvements to the blast-furnace, the daily output of which is now 110–120 tons of ferromanganese or 160–180 tons of spiegeleisen. Further modernization of the second blast-furnace is also planned. Finally, brief notes on operating procedures are given.—G. F.

FOUNDRY PRACTICE

The Significance of the Weichelt Diagram in the Manufacture of Pearlitic Cast Iron. M. Stap. (Metalen, 1950, vol. 4, June, pp. 201–212). [In Dutch]. The saturation point *Sc* (*i.e.*, the relationship between the carbon content of the casting and that of the eutectic point ($Sc = \%C/4{\cdot}1$) is used to determine the influence of the total carbon on the tensile strength of the cast iron. The lower the degree of saturation, the higher the tensile strength. Other formulæ to illustrate the effect of silicon on the degree of saturation are discussed. Phosphorus has a similar, almost greater, effect than that of silicon. The influence of manganese is much less. The relationship between the degree of saturation and the Brinell hardness and structures is illustrated. In 1933, Weichelt developed an improved Maurer's diagram. In the Weichelt diagram, the upper limit of the phases is cut off by a line running downwards to the right. At the eutectic point 4·2% C is dissolved in molten iron. With increasing silicon content, this solubility is lowered so that, at 3·5% Si, about 3·5% C is soluble. The descending line thus shows the eutectic point in relation to the silicon content. This relationship is not shown by the Maurer diagram. When a high carbon iron is cooled slowly, graphite is deposited in the liquid due to the decreasing solubility. This 'scum graphite' can be skimmed off the surface. If cooling is too rapid, the graphite remains in the iron in coarse lamellar form, giving poor strength.

Weichelt diagrams clearly show the relationship between the graphitizing effect of carbon and silicon and the composition. For different contents of one of these elements, the content of the other necessary to give a certain structure can be determined. An examination of the Weichelt diagram shows that, as the diameters of the specimens decrease, all phases are diminished except that of the white iron, which increases. This tendency for the increase in the formation of white iron with diminishing thickness is borne out in practice.

By means of the Weichelt diagram, the relationship between the diameter of a round test bar and the wall thickness of a casting can be determined when both the specimen and the casting have a given structure. The diagram is useful for determining compositions of cast iron for given purposes and can be extended to cover the effects of additional alloying elements.—R. S.

Outline of Inspection for Pearlitic Malleable Castings. D. T. Martin. (Transactions of the American Foundrymen's Society, 1950, vol. 58, pp. 692–698). The procedures and responsibilities of foundry inspection personnel in ensuring the quality of the finished castings, with due regard to subsequent machining operations and the diversity of the range of castings produced, are discussed as functions of plant economy. The checking of physical properties on a mass-production scale, the layout of the instruments, and the use of specific methods for special requirements are also discussed. Examples are provided.—E. J. D. S.

New Cupola Design. (Foundry, 1950, vol. 78, June, pp. 82–85, 193, 196, 199). The various stages in the development of cupola design and performance carried out at the Ford Motor Company, Ltd., England, are described. These include the construction of a backed melting zone, use of exposed water-coolers, elimination of the well below the melting zone, construction of a slag trap to permit continuous tapping, and the use of a basic lining to facilitate sulphur removal.

E. J. D. S.

The Pressurized Cupola. (Foundry, 1950, vol. 78, Sept., p. 127). The cupola described is fitted with a removable orifice ring at the charging-door level which permits a constant air velocity through the charge. In operation, the cupola is similar to an air receiver filled with air at constant pressure whilst the air is discharged through a calibrated orifice at constant velocity. Benefits claimed are: Operation less dependent on coke size; easier control of air volume; improved combustion and higher metal temperature; uniform lining erosion; and less smoke and fly ash.—E. J. D. S.

Auxiliary Oxygen Applied in 72 inch Production Cupolas. F. J. Webbere. (American Foundryman, 1950, vol. 17, June, pp. 40–44). The present report submits operating data on using oxygen-enriched blast in cupolas. Initial coke bed height was 52 in. above the tuyeres, requiring 5800–6200 lb. coke. No additional oxygen was supplied until about 2 hr. after the blast was turned on. Cupola performance and the properties of the irons made were studied using blast containing 21·9, 22·6, and 23·7% of oxygen. An optimum performance was observed when less than 2% oxygen enrichment was used, a 12½% reduction in coke consumption per ton of iron being achieved with 1% enrichment. Greater variations in carbon and silicon contents of the irons were observed when additional oxygen was present than when absent from the blast, but their mean values were about normal. With additional oxygen, less slagging at the tuyeres occurred and the height of the melting zone was reduced, giving a more local penetration of the lining. The advantages of oxygen-enriched blast in these large cupolas do not seem as great as those for smaller types, although refractory loss and unit cost of oxygen are minimized. However, the maximum effects of additional oxygen appear to occur at a lower order of enrichment in a large cupola and, consequently, may bring the economies more into line with those for the smaller variety. Cheap oxygen production is discussed.—E. J. D. S.

Operation of the Cupola. W. W. Levi. (Transactions of the American Foundrymen's Society, 1950, vol. 58, pp. 1–19). The elements of cupola practice including equipment, front-slagging, balanced-blast control, moisture content control of blast, mechanical charging equipment, inoculants, and carbon equivalent and its calculation are presented.—E. J. D. S.

Equilibrium and Air Preheating Trials in a Cupola 900 mm. in Diameter. P. G. Maceraudi. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 133–141). [In French]. The objects of these trials were to study the behaviour of the air feed under normal uncontrollable conditions and under conditions of equilibrium. In the air preheating trials, only the influence of low temperatures was studied (about 150° C.). Air equilibrium trials were carried out on a 900-mm. dia. cupola with six rectangular tuyeres. With regular air distribution amongst the tuyeres and freedom from clogging it was found that there was a more uniform wear of refractories, more uniform combustion, and an

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increase of 20° C. in the temperature of the iron. Optimum rate of air flow was 12 to 13 m./sec. In the preheated air trials, the Moore system of preheating was used. The temperature of the iron was increased by 30° C.; 15% coke economy was effected; tuyere operation was improved; output per hour was increased by 7%. Details of heat-transfer conditions are given.—R. S.

Cupola Operation: The Proportional Blast System. N. P. Piennaar. (Iron and Steel, 1950, vol. 23, Apr., pp. 111–115). The conventional constant blast system of cupola operation has a number of inherent disadvantages resulting from the initial period of overblowing. The author describes how these may be obviated by operating under the proportional blast system of controlled variation in air supply, which is based on proportioning the cupola blast so that equilibrium between air supply and melting rate is maintained at all times during melting. Theoretical and practical details of the new system are given, and the results of experiments show that melting may be made to take place to a definite predetermined schedule, which may be reproduced consistently. The other enumerated advantages of the new system are: (1) Lower metal losses; (2) less severe burn-out; (3) use of a lower coke bed; and (4) improved metal temperature. No special equipment is required apart from the air flow controller.—G. F.

Origin and Control of Carbon in Ferrous Alloys. H. A. Schwartz. (Foundry, 1950, vol. 78, Aug., pp. 97, 135–139). In this article, which is a chapter from the author's book "Foundry Science," the reactions governing the movement of carbon in the blast-furnace, cupola, and Bessemer converter are considered.—R. A. R.

Section Size Relationships in Nodular Iron. G. Vennerholm, H. Bogart, and R. Melmoth. (Transactions of the American Foundrymen's Society, 1950, vol. 58, pp. 174–183). Two types of nodular iron were investigated: One a high-duty iron made from blast-furnace pig, the other a highly ductile iron made from an electric furnace pig. The magnesium contents varied between 0·025 and 0·09%, the magnesium being added as 6% magnesium–copper–ferrosilicon alloy inoculated with 0·3% silicon as 75% ferrosilicon. The tensile strength of the first type of iron remained generally constant after a complete nodular structure was formed, with a tendency to reach a maximum at about 0·08% Mg. A general increase in yield strength was observed after the first appearance of nodules, and a loss of strength as the casting section increased was evident with bath properties. The elongation of this iron (containing 0·92% Mn and 0·12% P, average) was apparently not affected by either section size or magnesium content. In all examples the elongation was about 1%. When annealed for 2 hr. at 1750° F. the strength of the iron increased substantially with increasing magnesium content. The impact strength of the iron thus annealed rose rapidly, reaching a high value at about 0·05% Mg and fell off at almost the same rate. Annealing at 1325° F. brought the impact strength down by over 50%. The decrease in this property was very noticeable with increase in section. The second type of iron was similarly investigated.—E. J. D. S.

Economic Considerations in Producing Magnesium-Containing Iron. D. J. Reese. (Foundry, 1950, vol. 78, May, pp. 120–125). Production costs, including those determined by the choice of metallurgical requirements, composition of raw materials, anticipated output, foundry control costs, and property specifications are reviewed and discussed.—E. J. D. S.

Brake Drum Materials. F. J. Walls. (Foundry, 1950, vol. 78, Aug., pp. 82–84, 118–119). A continued shrinkage of the inside diameter of low or medium carbon aircraft brake drums has been found to occur when they are subjected to high energy inputs, necessitating frequent regrinding to give lining clearance. The use of high-carbon cast irons reduced this shrinkage, and attempts to improve the resistance of cast irons to heat checking resulted in the following specification for drums cast statically: C (total) 3·70–3·90%, Si 1·10–1·30%, S 0·06% max., P 0·10% max., Mn 0·60–0·80% max., Mo 0·40–0·60%, Ni 1·90–2·10%; tensile strength 30,000 lb./sq. in. min.; Brinell hardness 200–240; stress-relieving treatment at 1000° F. for 1 hr., furnace cooled. With increased braking loads resort was had to bimetallic drums with a composition of: C (total) 3·70–3·90%, Si 1·45–1·65%, S 0·10% max., P 0·20% max., Mn 0·50–0·70%, Cr 0·30–0·40%, Mo 0·30–0·40%, and Ni 1·35–1·55%. A summary of 17 different heavy-duty brake drum compositions and their properties from seven companies is given as: C (total) 3·15–3·70%, Si 1·5–2·55%, Mn 0·40–0·90%, S 0·15% max., P 0·275% max., Cu 0–1·25%, Cr 0–0·80%, Mo 0–0·90%, Ni 0–1·55%; Brinell hardness 170–302 on bar, 170–248 on casting; tensile strength 30,000 lb./sq. in.; pearlitic structure.—E. J. D. S.

Producing Textile Machinery Castings. P. Dwyer. (Foundry 1950, vol. 78, Aug., pp. 78–81, 190–192). The methods and equipment employed in a foundry producing textile machinery castings are discussed.—E. J. D. S.

Effect of Oxidation in Cupola Melting on Annealability of Malleable Iron. M. Tilley. (Foundry, 1950, vol. 78, May, pp. 142–143, 313). Most cases of prolonged annealing times for cast iron, and misruns, shrinks, and hot tears can be traced to excessive oxidation of the iron in the cupola. The severity of oxidation with respect to graphitization rate is indicated by the reduction in the number of graphite nodules. Curves are given to show the effect of the oxidizing conditions on the nodule count, in terms of the oxidation of silicon. As the silicon charged is oxidized the corresponding nodule count falls rapidly and the effect is more pronounced above 25% silicon oxidation. With oxidation maintained at this percentage or less the nodule count was normal and no castings were rejected. However, silicon oxidation of nearly 40% was accompanied by slight whitening of the iron and the rejection of 14% of the castings. The judicious use of deoxidizers is discussed.—E. J. D. S.

Influence of Zirconium on Malleablization of White Cast Iron. H. E. Bleil and J. Varga, jun. (Foundry, 1950, vol. 78, Oct., pp. 94–99). A series of zirconium-bearing white irons was made by adding commercial ferrozirconium to an iron containing 2·46% C, 1·12% Si, 0·35% Mn, and 0·098% S, giving zirconium contents ranging from 0·054 to 0·329%. By annealing treatments these alloys were used to study the effect of zirconium on the time necessary to promote graphitization, the complete solution of cementite during the first stage of annealing, and any stabilization of pearlite during the second stage. The investigation yielded apparently contradictory evidence in that (1) the time required for complete solution of cementite at the upper critical temperature increased with zirconium content; and (2) primary graphite increased with zirconium additions. The authors believe that: (*a*) During cooling and solidification of a white iron zirconium acts as an active graphitizer, producing primary graphite of an agglomerated structure; (*b*) the annealing time for white iron is greatly increased at the upper critical temperature with increasing additions of zirconium; and (3) these additions have no effect on the pearlite in the second stage of annealing. A brief review of the literature on the effect of zirconium on the behaviour and properties of cast iron is included.—E. J. D. S.

A Summary of the Quantitative Effects of Some Factors on the Annealing of White Cast Iron. R. Schneidewind. (Transactions of the American Foundrymen's Society, 1950, vol. 58, pp. 202–207). The effects of soaking temperature on first-stage annealing rates of identical castings are shown by a graph in which the log of time is plotted against the reciprocal of temperature. On the basis of a selected standard annealing treatment an empirical formula is employed to calculate the time required to anneal an identical casting at a different temperature. The characteristics of second-stage annealing are similarly treated. A formula was also derived to express the times of annealing for an iron heated to its soaking temperature at two different rates. The effects of superheating, deoxidation, section size, silicon content, and manganese content are summarized and expressed by formulæ where the collective evidence of various workers, and the author's, justify them. It is said to be impossible to compute annealing rates from chemical composition, and only the exact influence of a few factors is understood. However, if the data examined be carefully derived it is claimed that approximate predictions of annealing rate for castings under similar conditions can be made.—E. J. D. S.

Steel Casting Production. (Automobile Engineer, 1950, vol. 40, Aug., pp. 278–280). Methods employed by Leyland Motors, Ltd., to produce steel castings are described. The main production ranges from 1½ to 120 lb. per casting. Centrifugal as well as conventional casting methods are employed. For example, a cluster of 20 body-mounting brackets weighing 14 lb. each is arranged in one mould which is rotated at 180 r.p.m. Inspection is very strict and, where quantities are sufficiently large, jigs incorporating gauging

points are used; these enable incorrect dimensions and distortion to be instantly detected.—R. A. R.

Contribution to the Study and the Preparation of Moulding Sands. L. J. Petrzela. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 219–233). [In French]. This is a French version of a paper which appeared in Hutnické Listy, 1950, vol. 5, Sept., pp. 353–359; Oct., pp. 406–412 (*see* Journ. I. and S.I., 1951, vol. 167, Mar., p. 337).

Reproducibility of Foundry Sand Tests. B. H. Booth, P. C. Rosenthal, and H. W. Dietert. (American Foundrymen's Society, 1950, May, Preprint No. 27). The problem of reproducibility of sand testing methods in practice was reported on by S. Walker in 1941, and subsequently the American Foundrymen's Society organized a detailed investigation to be carried out in ten different laboratories. The results and criticisms of the investigation are reported. Whilst some of the tests reproduced very well, it was observed that more attention to the maintenance of apparatus, the fulfilling of test instructions, and to the personnel, was required in order to improve the accuracy and reproducibility of sand testing.—E. J. D. S.

Treatment of Bond Clays for Foundry Sand. A. E. Pavlish. (American Foundrymen's Society, 1950, May, Preprint No. 24). The purpose of the investigation reported in Part I was to modify the properties of a Mississippi bentonite and a Lawrence plastic fireclay by base exchange reactions. The base exchange capacities were respectively 6·4 and 11·6 milliequivalents per 100 g. In Part II are given the results of an investigation to determine the effectiveness of various lignin sulphonates in increasing the strength of clay-bonded sand.—E. J. D. S.

Ceramic Molds for the Foundry. T. A. Dickenson. (Foundry, 1950, vol. 78, Mar., pp. 84–86, 144). Permanent moulds of such materials as quartz glass, porcelain-enamelled steel, and specially coated slip-cast clay are described. Applications are mainly confined to metals of moderately low melting point.—E. J. D. S.

A Universal Blow Plate. W. P. Morton. (Foundry, 1950, vol. 78, Apr., p. 177). The design for a single blow plate to be used on every core box, thereby making the plate a fixed part of the machine, is described. The technique produced much better cores, almost eliminated the necessity for venting core boxes, except in inaccessible corners, and removed the tendency to economize on blow plates by making one plate do for jobs to which it is unsuitable. The success of the blow plate discussed depends on exchangeable bushings that function as blow holes or vents.—E. J. D. S.

Influence of Blowhole Diameter, Vent Area and Air Pressure in Core Blowing. H. M. Gade. (Foundry, 1950, vol. 78, Mar., pp. 82–83, 156–160). Two core boxes were used in the experiments—the first a conventional type, the second of wire mesh. The total vent area of the former was 0·498 sq. in., whilst the vent area of the latter was almost equal to the area of the box, with the exception of the top 1 × 8 in. side which was in contact with the blow plate. Weight measurements were used to indicate the efficiency of sand packing in the core boxes. Air pressures were varied between 25 and 75 lb./sq. in. It was concluded that for blow-hole diameters smaller than $\frac{3}{4}$ in. the normally vented core box yielded heavier cores than the box with the maximum venting. For blow holes $\frac{3}{4}$ in. in dia. and larger the results obtained with both boxes were equivalent within the experimental error. Increasing air pressure increased core weight but the advantage obtained by successive increases in the above pressure range became progressively less. Core boxes were filled satisfactorily at the lowest pressure.—E. J. D. S.

Standard Data for Bench Coremaking. H. R. Williams. (American Foundrymen's Society, 1950, May, Preprint No. 18). A detailed review of the development of 'standard' or specific working data for bench coremaking is presented. Illustrations are given from the time-study of coremaking operations in a jobbing steel foundry.—E. J. D. S.

Machine Molding Large Dry Sand Cores. M. J. Kellner. (Foundry, 1950, vol. 78, Apr., pp. 146–148). A normal moulding machine with a jolt-squeeze roll-over action was adapted to the production of large dry sand cores weighing 50 to 350 lb. Improved core quality and reduced costs are claimed for this process, which is described and illustrated. E. J. D. S.

Phenolic Resin Core Binders. J. E. McMillan and J. A. Wickett. (American Foundrymen's Society, 1950, May, Preprint No. 20). The effects of cereal, resin, and water on core properties were investigated. A commercial cereal binder was used to produce green strength but Bentonite binders were avoided because they were found to decrease the baked strength of resin-bonded cores. A water-soluble liquid phenolic resin was selected for the tests. Green strength, baked tensile strength, and scratch hardness (Dietert units) were determined for silica sand cores made up with cereal and resin in different proportions. The effect of water additions was also studied. The test results are said to be reproducible in foundry practice.—E. J. D. S.

Core Oil Evaluation Method. R. H. Olmsted. (American Foundryman, 1950, vol. 17, June, pp. 58–60). Unnecessarily expensive core oils may be used for want of a basis for core oil selection. The baked shear-strength test was chosen to evaluate the properties of various baked core oils, and consequently to select the most economic oil. However, the advantages of the best materials and mixture ratios depended largely on the efficient working conditions of the mixing equipment.—E. J. D. S.

Steel Foundry Core and Molding Sands. J. H. Hall. (Foundry, 1950, vol. 78, Apr., pp. 79, 180–200; May, pp. 144, 145, 273–286; June, pp. 100, 101, 232–243; July, pp. 75, 212; Aug., pp. 85, 119–120; Sept., pp. 113, 240–245; Oct., pp. 103, 226–230). Properties of moulding sand for the production of steel castings, tests for determining permeability, green and dry strength, and various other sand control measures, including grain shape and distribution, are discussed. The effects of property variations on the penetration of liquid metal into moulds and cores, the function of cores, dry and green sand moulding practices, and sand reclamation are also considered.—E. J. D. S.

Fayalite Reactions in Sand Molds Used for Making Steel Castings. R. E. Savage and H. F. Taylor. (American Foundrymen's Society, 1950, May, Preprint No. 29). A study of steel-casting/mould-interface reactions is presented. Fayalite was found by X-ray diffraction analysis to be the only product formed by these reactions. No other elements were found in the interface layer of shop and laboratory samples. Fayalite is said to be formed by oxidation of the iron and by subsequent reactions of this oxide with the silica sand. A laboratory method for studying the interface reactions is described and the thermodynamic considerations are briefly set out.—E. J. D. S.

Tenth Annual Report on the Investigation of Steel Sands at Elevated Temperatures. R. G. Thorpe, P. E. Kyle, and J. P. Fraser. (Transactions of the American Foundrymen's Society, 1950, vol. 58, pp. 133–143). Load-deformation testing is described and the stress–strain characteristics of two synthetic sand mixtures at elevated temperatures are presented graphically. From preliminary tests it is suggested scab-forming tendencies of moulding sands may be predicted on the basis of the relationship between the properties of expansion and hot deformation.—E. J. D. S.

Effect of Moisture on Core Sand Mixtures. O. J. Myers. (Transactions of the American Foundrymen's Society, 1950, vol. 58, pp. 557–562). Four mixtures were studied: (1) Sand and water; (2) sand, water, and core oil; (3) sand, water, and cereal binder; and (4) sand, water, core oil, and cereal binder. The following tests were conducted to show the effects of moisture content: Density, permeability, green strength, baked tensile strength, bakability, and hardness. It is suggested that lack of core-sand control for incoming wet sand is a more serious deficiency than the segregation that could be associated with dried sand.—E. J. D. S.

Controlled Sand Produces Quality Castings. B. H. Booth. (Transactions of the American Foundrymen's Society, 1950, vol. 58, pp. 52–62). The purpose of the paper is to demonstrate the value of a standard sand testing control programme. Many casting defects have been traced to inadequate sand control. Sand qualities and testing procedures are discussed. E. J. D. S.

A Study of the Effect of Various Binders and Additives on Hot Strength of Molding Sands. R. E. Morey and C. G. Ackerlind. (Transactions of the American Foundrymen's Society, 1950, vol. 58, pp. 411–421). Simplified synthetically bonded sand mixtures containing bentonite as the primary binder were tested for hot compressive strength at 200 to 2500° F. A reference sand mixture containing 2% bentonite

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and 3% water was used for comparison with mixtures containing other clays and to evaluate the effects of secondary sand binders and other additions. The clay used established the general pattern of the hot strength temperature curve. Clay binders produced relatively high hot strengths in comparison with other binders, especially in the pre-fusion range. Hot strength increased with increase in both clay and water contents in the range studied. Organic binders were studied both as a single binder and as a secondary binder in combination with the bentonite. These secondary sand binders modified the strength of the clay binder, generally by increasing strength in the 400–800° F. range. At higher temperatures the effects were shown in increases and sometimes in decreases in the strength developed by the clay binder. Selected additives which did not contribute to green strength were also studied. Additions of silicon flour and iron oxide increased hot strength, whilst additions of wood flour decreased it.—E. J. D. S.

What the Foundry Expects of the Pattern Shop. C. V. Nass. (American Foundrymen's Society: Foundry, 1950, vol. 78, May, pp. 132–133, 306–309). The demands imposed by different classes of foundry on their respective pattern shops, and the foundry departmental relationships are reviewed and discussed. The procedure for estimating production costs, without a time-study department, is outlined, and 24 salient items of instruction for foundrymen and patternmakers are appended.—E. J. D. S.

How to Build Strength into Large Patterns. A. E. Wells. (American Foundryman, 1950, vol. 17, June, pp. 38–39). Important features of strong and rigid wooden pattern construction are enumerated.—E. J. D. S.

A Study of the Principles of Gating. K. Grube and L. W. Eastwood. (Transactions of the American Foundrymen's Society, 1950, vol. 58, pp. 76–99). The investigation reported was limited to pouring methods, the design of pouring box, sprue, and horizontal runner and gate systems. The experimental technique employed models made of lucite, with water or Wood's metal as the pouring liquid. High-speed photography was used to observe and record the effect of various gating designs. Pouring technique and gating design should be such that the gating system can be completely and quickly filled before any liquid enters the mould cavity, and that it can be kept full during the entire pouring operation. If the flow channel can be filled quickly and kept full, gas entraïned from the vortex, aspiration, and gas entrapped during the initial part of the pouring can be avoided or minimized. It is therefore necessary to avoid abrupt changes in direction of flow or in cross-section of the flow channel from the top of the sprue to the mould cavity. The one location where such changes are desirable is the sprue base or that portion of the runner under and adjacent to the sprue.—E. J. D. S.

Heading and Gating Practice. F. B. Riggan and H. Schulte. (Foundry, 1950, vol. 78, May, pp. 134–137). The important influence of heading and gating on quality, cast, and yield of castings in the steel foundry is discussed and illustrated.
E. J. D. S.

Radiator Section Molds Made Four per Minute. P. Dwyer. (Foundry, 1950, vol. 78, Apr., pp. 70–75, 201–202). A description is given of the production of cast-iron sectional boilers and radiators in a highly mechanized foundry using automatic units. Iron is melted in one of two 55-in. cupolas operated to deliver about 100 tons of iron per day. Each mould contains three to five radiator sections weighing 50 to 70 lb. and the average production on each unit is 1300 moulds per 8-hr. shift.—E. J. D. S.

Which Molding Method? P. Dwyer. (Foundry, 1950, vol. 78, Apr., pp. 88–89, 126, 128). Several different methods may be employed to mould a given casting but the one selected depends to a great extent on the facilities of the plant and the experience of the personnel. The author discusses various alternative procedures for moulding a specific casting.—E. J. D. S.

Plastic Bonded Shell Molds Used in New Casting Process. B. M. Ames, S. B. Donner, and N. A. Kahn. (Foundry, 1950, vol. 78, Aug., pp. 92–96, 206–217). *See* "Metal Parts with High Accuracy and Finish Produced by New Casting Process," Journ. I. and S.I., 1951, vol. 168, May, p. 97.

New Process Casts Soil Pipe at High Rate. W. G. Gude. (Foundry, 1950, vol. 78, May, pp. 128–131, 258, 260). An automatic centrifugal pipe-casting machine is described. Sections of pipe are cast in sand-lined flasks, and the machine has a self-contained sand handling system. The complete installation is electronically controlled. In approximately 2 min. four 5-ft. lengths, each weighing 40 lb., 4 in. inside dia., can be produced. The machine is capable of making over 100 lengths/hr., whilst pipe down to 2 in. in dia. can be made. Apart from labour in the core shop, only five men are required as machine operators. The products are of uniform grain size and thickness and no subsequent annealing treatment is necessary. A detailed description of the machine and its operation is included.—E. J. D. S.

Casting Grinding Balls Continuously. P. M. Payne and F. G. Steinebach. (Foundry, 1950, vol. 78, Mar., pp. 70–73, 217–219). Carbon–manganese–molybdenum steel balls for grinding purposes are produced automatically and at a high production rate in the casting machine described. Pure copper water-cooled moulds are used.—E. J. D. S.

The "Lost Wax" Process of Precision Casting. J. S. Turnbull. (Proceedings of the Institution of Mechanical Engineers, 1950, vol. 162, No. 1, pp. 66–74). The author describes the 'lost wax' process by which metal castings with a good surface finish to an accuracy of $\pm$ 0·002 in. can be produced. The tool costs are relatively low compared with the costs involved in alternative methods of manufacture, the die cost being a function of the number of castings required. At present scrap from the manufacture of gas turbine blades is less than 30%; the author believes it may be less than 10% in two years' time.—R. A. R.

Time Study and Standards Aid Foundry Production Planning. J. J. Farkas. (American Foundryman, 1950, vol. 17, June, pp. 45–47). Foundry planning and scheduling, analysed by time-study methods, are discussed.—E. J. D. S.

Foundry Cost Reduction through Motion Study. M. E. Mundel. (Metal Casting Conference: Foundry, 1950, vol. 78, Mar., pp. 78–81, 136). Specific instances in which the motion study of foundry operations has resulted in the reduction of costs are given. The changing of blow plates and mechanical blasting are operations selected to demonstrate the time and motion study procedure which effect the financial savings.
E. J. D. S.

Handling Materials at the Shakeout. R. H. Herrmann. (Foundry, 1950, vol. 78, Apr., pp. 90–95, 229, 230). The moving of materials and items of equipment to and from the shake-out department, and the extent to which the various operations can be mechanized, depends largely on the type of casting, volume of production, and whether the castings are poured continuously. Different types of equipment for handling sand, castings, boxes, etc., are described.—E. J. D. S.

Handling Materials in the Cleaning Department. R. H. Herrmann. (Foundry, 1950, vol. 78, Sept., pp. 102–107). The handling of castings of various sizes and in different quantities in, to, and from cleaning and fettling departments is discussed and illustrated.—E. J. D. S.

Modern Use of Exhaust Ventilation. J. G. Liskow and C. J. Berquist. (Foundry, 1950, vol. 78, Sept., pp. 108–112, 247, 248). The ventilating and extractor system covering each section of a grey-iron foundry with a melting capacity of about 52 tons/hr. is described. Outside air pollution is minimized by passing all dust-, smoke-, or fume-laden air through extractors, including the stack gases from the cupolas. The effective volumes of exhaust gases, etc., from the various foundry units are given. The operation of the system is discussed. It was found that over a 60-day test period inspection, cleaning, and maintenance involved an average of not more than 12 man-hours per 8-hr. shift for dust collectors, sluicing systems, and settling and dewatering tanks.—E. J. D. S.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Cementation by Carbon and Nitrogen. J. Pomey. (Revue de Métallurgie, 1950, vol. 47, Sept., pp. 637–657; Oct., pp. 727–738). Cementation by carbon monoxide, and the effects of hydrogen and free carbon are discussed. Hydrogen increases the speed of reaction but lowers the concentration of carbon in the layer. In cementation by methane, an excess of hydrogen is needed to prevent pyrolysis and the addition of a higher hydrocarbon such as 0·5–3·5% propane is advantageous. Cementation simultaneously by carbon monoxide and methane has the advantage of being autostabilized owing

to the opposing effects of pressure and temperature on the reactions $2CO \rightleftharpoons CO_2 + C\gamma$ and $CH_4 \rightleftharpoons 2H_2 + C\gamma$. In carbonitriding, ammonia can nitride directly by dissociation at 600–750° C. but at 850° it acts indirectly by forming hydrogen cyanide in reaction with methane and ethane. The general law of diffusion is derived and the case of ideal cementation considered. Modifications are made to include the effects of varying cementation in the surface, change of diffusion coefficient with concentration, and activity. The chemical factors affecting activity and the diffusion coefficient are discussed, also the variation of the coefficient with temperature, and the influence of nitrogen on the diffusion of carbon. Grain size and orientation have no effect on diffusion. The process of nitriding is considered with the effect of curvature of surface, temperature, concentration of aluminium in the surface, and time. Cementation is essentially a non-equilibrium process and is very complex. The theory for the simplest case requires many adjustments before agreeing with practice.—A. G.

Determination of Case Depth in Case-hardened Articles. A. Kühnert. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Nov.–Dec., pp. 437–440). Comparative tests have been carried out to ascertain the best method for determining case depth. The most accurate methods were those involving Vickers hardness measurements on cross-sections and examination of etched microstructures. Then followed examination with a travelling microscope of macro-etched specimens and Vickers determinations on oblique sections. The most inaccurate method was that of examining fractures. An accurate means of determining case depth using a 'limiting test load' diagram is described. This method is not suitable for case depths over 0·5 mm.—J. P.

Statistical Assessment of the Accuracy of the Calculation of Carbon Penetration in Case-hardened Steels. H. Schrader and Ruth Moufang. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Nov.–Dec., pp. 381–393). Carburization experiments on 270 samples of alloy steel have shown that the conventional diffusion theory can be employed to describe the carburizing of steel, except in a surface layer which is approximately one-fifth of the case depth. The diffusion coefficient D is independent of the carburizing agent, but is an exponential function of the reciprocal of the absolute temperature. Scatter in the determined values of D and of the carbon content of the surface layer c_0 may cause errors of $\pm$ 75% in calculating depths of penetration of the order of 1 mm., though use of the most probable values of D and c_0 may reduce the inaccuracy. The use of D-values, determined from short-time tests, for calculations relating to long carburizing times, may lead to considerable errors. A diagram has been drawn to indicate penetration depth at different temperatures and carburizing times under normal conditions.—J. P.

An Analysis of Flame Hardening. E. F. Green. (Steel Processing, 1950, vol. 36, Sept., pp. 455–459). In recent years the flame-hardening process has been developed to a state of great mechanical refinement. This article is a general description of the equipment, methods, and advantages of present-day techniques.—P. M. C.

A Guide to Flame-Hardening. K. Boeckhaus. (Schweissen und Schneiden, 1950, vol. 2, Apr., pp. 73–78). Flame-hardening, using a set of burners followed by a row of water jets for quenching, is described. Steel-castings containing 0·35–0·70% of carbon and a few alloy steels can be flame-hardened by this method.—U. E.

High Frequency Heating in Industry. K. A. Zandstra. (Journal of the Society of Engineers, 1950, vol. 41, Oct.–Dec. pp. 149–172). After explaining the theory of induction heating the methods of producing high-frequency currents are described with special reference to valve-driven generators. The advantages of this generator include precise localization of the heating, stability of electrical characteristics over long periods, and easy adaptability for a large variety of articles from soldering up to the most precise heat-treatment. The design of heating coils is discussed and numerous applications of this form of heating are illustrated.—R. A. R.

Induction Heating in the Steel Industry. E. H. Browning. (Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 82–89). Developments in induction heating processes from 1939 to 1945 are discussed. The two forms of induction heating equipment for the heating of metal sheet, strip, and slabs are described. These are longitudinal and transverse flux heating. In the first type the induced current flows essentially around the periphery and perpendicularly to the longitudinal axis of the metal being inductively heated. In the second type the current flows across the metal. The relative merits and fields of application of both forms of induction heating are discussed. Induction heating lends itself to continuous production, and its application to the annealing of steel strip and its use in a skelp heat line are considered. It could be used in conjunction with fuel-fired furnaces to increase the speed of pipe mills.—M. D. J. B.

Comparison of Gas and Bath Nitriding. H. Schrader. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 185–227). In a comparison of gas nitriding in ammonia and nitriding in cyanide salt baths, different nitriding effects are found corresponding to the different reactions. The loss in core ductility of different types of constructional steel during nitriding and the influence of alloying elements upon their nitridability have been discussed. Factors affecting the toughness of the nitrided layer have been examined with different test methods. Of these, a through-nitrided hollow torsion specimen has proved to be the most reliable. As the nitrided layer has high hardness and temper-resistance, nitrided tungsten and molybdenum-free tool steels attain cutting efficiencies superior to non-nitrided high-speed steels. Nitriding effects an improvement in fatigue strength, which is attributable more to the high hardness of the external zones than to the compressive stresses caused by an increase in volume. Bath-nitrided high-speed steels have thinner cases than gas-nitrided chromium–aluminium steels. Except in the case of aluminium-bearing steels, the same steel composition is found to yield similar penetration effects by both methods of nitriding. Nitrogen contents of the external zones are considerably higher for gas-nitriding than for bath-nitriding. Bath-nitriding effects simultaneous carburization in steels other than those highly alloyed. Nitriding with hydrogen-cyanide-containing gas has an effect similar to that of bath-nitriding. Improved corrosion resistance of nitrided surfaces is expected when produced by bath-nitriding on account of the lower nitrogen and higher carbon contents.

D. H.

Gases in Steel—Nitrogen and Nitriding. A. Fry. (Instituto del Hierro y del Acero, 1950, Supplement to vol. 3, July–Sept., pp. 36–47). [In Spanish]. Under certain conditions, nitrogen produces solid, stable compounds in steel at low temperatures. The laws governing the absorption of nitrogen and oxygen by steel are somewhat analogous. The solubility of nitrogen in iron at atmospheric pressure and in relation to temperature is illustrated. Nitrogen penetration curves for carbon steels are given. The structures obtained after nitriding in relation to nitriding temperatures are shown. The developments of the principles on which the nitriding process was developed are outlined. Advantages and applications of nitriding are described and, finally, the influence of alloying elements on the hardness obtained by nitriding is examined.—R. S.

Corrigenda

In the February *Journal*, p. 219, col. 2, abstract 3, line 6, for 'decomposition' read 'deposition'.

In the abstract entitled 'A Static Magnetic Amplifier for Regulating Circuits' on p. 348 of the March *Journal* the second author's name was omitted. The two authors were H. E. Larson and T. Dunnegan, jun.

Twin Batch-Type Carbonitriding Furnaces Precision-Harden Transmission Pinions. A. H. Allen. (Steel, 1950, vol. 127, Sept. 4, pp. 84–85, 104). The precision hardening installation at the Chevrolet-Cleveland transmission plant is described. Two furnaces each treat 350–450 lb. on a 2½-hr. cycle, surface hardness is to Rockwell A80 with a martensite case depth in the range 0·007–0·010 in. Close control of the atmosphere and rapid heating are features of the equipment.—A. M. F.

Stress Relief of Stainless 347 Investigated. L. H. Satz. (Iron Age, 1950, vol. 166, Sept. 28, pp. 78–81). Experiments show that the amount of stress relief that can be obtained in type 347 stainless (0·07% C, 18·09% Cr, 0·78% Cb, 13·3% Ni, 0·04% N, 1·3% Mn, 0·82% Si) is dependent more on temperature than on time. After 1 hr. at temperature, very little further stress relief is effected by increased soaking time. The percentage stress relief obtained at any

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one temperature, in the range 932° to 1652° F., is approximately the same whether the material is stressed to 75% or 39% of the yield strength.—A. M. F.

A Recent Installation for Bright Annealing. (Wire Industry, 1950, vol. 17, Oct., p. 831). A furnace installation for the bright annealing of wire is described. Manufactured by the General Electric Co., it consists of three vertical cylindrical furnaces rated at 90 kW. each, and 18 annealing containers, six of which are stored in thermally insulated pits which form recuperators. Newly charged containers are placed in these recuperators alongside hot containers recently removed from the furnace and are thus slowly preheated to about 200° C. so that lubricants are driven off instead of cracking, with a resulting improvement in finish. Partially burnt town gas is used as atmosphere. The furnaces operate at temperatures up to 750° C., each pot holds 20–25 cwt. of wire, and the power consumption is of the order of 200–220 units per net ton of charge.—J. G. W.

The Effect of Surface Conditions of Articles to be Hardened on the Cooling Process in Liquid Quenching Media. W. Peter. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Nov.–Dec., pp. 395–402). Tests have been carried out on soft iron spheres, the surfaces of which were bright, scaled, or coated with a layer of heat-treating salts, to determine the rates of cooling as a function of temperature when quenched from 800° C. in salt baths, aqueous salt solutions, distilled water, and hardening oils. When the surface is coated, the cooling process differs from that of a bright sphere only if the cooling action of the medium depends on evaporation, apart from a slight reduction in heat transfer due to the decreased thermal conductivity of the non-metallic layers. Thus in salt baths and oils there is no material change in the cooling process as compared with that of a bright surface. Under certain conditions of thickness and conductivity, layers of scale can suppress the formation of a blanket of steam around an article in aqueous media and so allow the most rapid cooling rates to occur at high temperatures. Salt layers show a similar effect only if they do not dissolve in the aqueous media. Hardening tests on three different steels of known transformation behaviour have confirmed these results.—J. P.

Hardened Steel Rolls : Their Manufacture and Use. C. W. Hirst and W. Shaw. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 229–251). Starting with the early history of rolling mills and rolls, the authors describe the properties required in rolls for the manufacture of non-ferrous sheets and strip. The steel composition used, care and precautions required during forging, machining, hardening, and grinding, are fully described. The types of failure encountered in rolls and their causes are fully explained. The heat-treatment of rolls is regarded by the authors as the most important aspect of manufacture and details are given of different methods of heating for hardening as well as precautions necessary at each stage.—D. H.

Quenching Media : Experimental Studies of Evaluation by the Jominy Test. H. E. Boyer. (Iron and Steel, 1950, vol. 23, May, pp. 177–180). This article describes experiments made to evaluate the power of quenching media, by reversing the principle of the Jominy test, steels of known hardenability being quenched in media which varied in composition and temperature. The apparatus is described, and the quenching media used were oil, pure water, and brine of 30% and 80% saturation. It is shown that water as a quenching medium becomes practically worthless above 150° F., whilst brine can be used at up to 190° F., owing to the retardation of the vaporization rate by the addition of salt. For most quenching purposes, the optimum temperature for oil is 150° F.—G. F.

Quenching of Steels. U. V. Bhat. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 51–84). The determination of centre and surface cooling curves is described and it is concluded that the cooling at the surface of steel specimens immersed in liquids moving at low velocities is seldom uniform. The effects of size and shape of material on the cooling in different media are discussed in detail and experimental results are considered. Coolants, water baths and sprays, dilute sodium hydroxide solutions, brines, and oils are dealt with. The effects on quenching of roughness of surface, scale thickness and adherence of oxide film are given. The implications of the term ' critical cooling rate ' are brought out in a discussion on the relation between cooling rates and depth-hardening properties of steels.

Hot Oil Quenching Reduces Distortion in Hardening of Steel Parts. K. Rose. (Materials and Methods, 1950, vol. 32, Nov., pp. 62–64). This new isothermal heat-treating procedure, called Marquenching, produces more uniform hardness, reduces residual stresses, and almost entirely eliminates warpage. The steel should be quenched to a temperature just below its M_s point, and then removed from the oil and allowed to cool in air. This retards the rate of formation of martensite, with the advantages referred to previously. Steels containing about 4% Ni may require several days to transform completely after the quench. The practical drawback to the method is that quenching oils rapidly deteriorate at the most suitable (metallurgically) temperatures—400 to 500° F. It is shown, however, that the method can be advantageously applied with quenching temperatures of about 250° F., at which the oil is stable.—P. M. C.

Tempering of High Carbon Steels. E. G. Ramashandran and D. P. Antia. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 131–145). The authors briefly discuss hardening with particular reference to the microstructures to be expected in the quenched product. The contiguous and simultaneous existence of martensite and retained austenite is explained by the nature of the transformation of austenite which transforms to a particular constituent depending on the temperature of transformation. The structural changes in martensite and retained austenite on tempering are discussed in some detail, and study of these changes by magnetometric, dilatometric, X-ray, and hardness methods have enabled the following conceptions to be put forth : (1) Tetragonal martensite as obtained on quenching yields on tempering in the range 83–160° C., a transition structure embedded in a ferritic matrix. (2) Retained austenite decomposes on tempering in the range 230–280° C. yielding a decomposition product similar to that obtained in the first stage. (3) The transformation structure obtained in the first two stages progressively forms cementite in the range 260–360° C. which on further heating reveals itself in the spheroidized form.—D. H.

FORGING, STAMPING, DRAWING, AND PRESSING

Heavy Commercial Forgings. G. T. Jones. (Mechanical Engineering, 1950, vol. 72, Aug., pp. 629–633). The author surveys the heavy forging industry. The production of several types of heavy steel forging made by the Carnegie-Illinois Steel Corporation is discussed in some detail. The control and planning which are necessitated by the use of heavy equipment are illustrated by reference to the production of steam turbine rotors, water wheels, generator shafts, steel sleeves for backing-up rolls, and anvil bases for hammers. D. H.

A Study of Forging Manipulators. M. A. Mercier. (Mémorial de l'Artillerie Française, 1949, vol. 23, No. 4, pp. 833–845). A description is given of handling machinery used in forging heavy items in Britain, Canada, and the U.S.A. The saving of manual labour and increases in output for a given press or hammer are stressed. Illustrations are given of several versatile types of forging manipulator.—J. J.

Progress in the Manufacture of High Quality Chains. A. Demanet. (Pact, 1950, vol. 4, June, pp. 248–250). Some general principles of modern heavy chain manufacture are outlined.—J. J.

Note on the Manufacture of Chains. F. Bayot. (Pact, 1950, vol. 4, Aug., pp. 319–325). A description is given of the methods of manufacture and testing of various types of chain. The following methods of manufacture are described and illustrated, welded link chains (hand forged, compression welded, and electric arc welded), weldless chains (stamped and rolled), and Galle chains.—J. J.

Drawing Tests on Alloyed Steel Wires under Different Operating Conditions. W. Lueg and A. Pomp. (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 977–984). The presence of a layer of common salt as lubricant carrier is advantageous in the drawing of alloy steel wire ; chromium–nickel stainless steel can be drawn by an eight-stage process.—J. P.

ROLLING-MILL PRACTICE

Mechanization of a Light-Section Rolling Mill. E. Schneider. (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 962–966). Improvements in the operation of a rolling mill are described. These include the continuous arrangement of the roughing train, repeaters from stand to stand, and automatic repeating

by means of roller devices. The use of tubular and suspended trough repeaters and a device for twisting the bar between stands have proved particularly valuable. Rolling schedules for rounds and flats are discussed.—J. P.

On the Elimination of a Defect in Rolling. A. Antonioli and R. Rolla. (Metallurgia Italiana, 1950, vol. 42, Nov., pp. 418–420). A description is given of a recurring defect found in silicon–manganese rolled spring-steel bars. The defects appeared as very small longitudinal markings, very shallow, which nevertheless gave rise to failures when the springs were tempered. The fault, which appeared to be more pronounced with certain casts, occurred when the bars were passed twice in succession through the rolls without being turned in the guides, thus giving rise to the markings along the neutral axis. Samples, taken after successive passes, in a case where the defect was particularly noticeable, have enabled the investigators to assess the causes of the fault and to improve the roll pass design. With the modified roll design the defect has been completely eliminated.—M. D. J. B.

Quality Control in Steelworks. R. Berger. (Pact, 1950, vol. 4, June, pp. 487–492; 1951, vol. 5, Feb., pp. 60–64). A description is given of the methods used to ensure that the quality of rolled steel products satisfies the specification for which they are designed, especially with regard to ultimate tensile strength and fatigue limit. The methods of testing are compared.—J. J.

Ultra-Fast Mill Helps Meet Strip Shortage. D. I. Brown. (Iron Age, 1950, vol. 166, Oct. 26, pp. 67–70). This article describes the new hot strip mill of the McLouth Steel Corporation's plant at Trenton, Mich. The outstanding feature of the plant is that finished strip 0·062 to 0·25 in. thick and up to 42 in. wide is produced without an intermediate reheating. A Continental twin-motor-drive blooming mill is used in conjunction with a Mesta 4-high reversing hot mill. The plant includes pickling and finishing lines.—A. M. F.

Strip Sheet: New Steelworks Installation in Northern France. S. H. Kahn. (Iron and Steel, 1950, vol. 23, Apr., pp. 121–124). A brief description is given of the new continuous strip-rolling plant and steelworks of the Société Lorraine du Laminage Continu in Northern France. Diagrammatic illustrations of the d'Ebange cold mill and Serémange hot mill are included. The plant will be ready for operation in 1952 and its output is expected to reach 2000 metric tons daily.—G. F.

Continuous Seamless Pipe Mill Employs One-Diameter Billet. J. L. Young. (Steel, 1950, vol. 127, Oct. 30, pp. 78–80). A brief description is given of the new seamless pipe mill of the National Tube Co., Lorain, Ohio. The mill has a rated capacity of 18,000 tons of 2 to 4-in. pipe a month. A. M. F.

MACHINERY FOR IRON AND STEEL PLANT

Economical Swarf Handling. H. M. Harman. (Power and Works Engineering, 1950, vol. 45, June, pp. 212–214). Swarf can be more easily handled, and up to 98% of the cutting oils recovered, if swarf crushers and oil extracting centrifuges are used. The author describes two different types of crusher with size ranges from 5 cwt. to 7 tons of swarf per hour, and feeding units and centrifuges of up to 5 cwt. capacity.—A. M. F.

Scrap Baling: Vauxhall Instal Motor Industry's Largest Press. (Iron and Steel, 1950, vol. 23, Apr., pp. 133–134). A description is given of the new hydraulic scrap metal baling press installed at the Vauxhall Motors factory. The machine, which bales the sheet metal scrap from the press shop, has doubled the company's baled scrap capacity. Working pressure is 2 tons/sq. in. and the machine handles steel sheet up to ¼ in. thick, producing bales 18 in. wide × 15 in. high × 32–48 in. long, weighing 5–10 cwt.—G. F.

Coal and Ore Shipping Plant. A. G. Thomson. (Mechanical Handling, 1950, vol. 37, Sept., pp. 346–349). Some factors affecting the design and erection of high-speed installations for the bulk shipment of coal and ore are given, and various types of plant are briefly mentioned.—D. H.

Handling and Storage of Basic Slag. G. E. Allin. (Mechanical Handling, 1950, vol. 37, Sept., pp. 364–365). The modern layout for the storage, conveying, and bagging of basic slag at the works of The Scottish Agricultural Industries, Ltd., Lincolnshire, is described.—D. H.

WELDING AND FLAME-CUTTING

Mass Production of All-Welded Deep-Drawn Gas Cylinders. A. I. Nussbaum. (Sheet Metal Industries, 1950, vol. 27, July, pp. 631–632). The author describes the plant and procedure in operation at Compressed Gas Cylinders, Inc., Los Angeles, where propane bottles to withstand 100 lb./sq. in. are produced at the rate of 90/hr. The cylinders, which weigh 93 lb. each, are made from two deep-drawn halves, each 21 in. long by 14 in. dia. by 10 gauge. The halves are automatically welded together with a flush submerged-arc weld using standard 'Lincolnweld' heads.—P. M. C.

Welding in Boilers. S. H. Griffiths. (Transactions of the Institute of Welding, 1950, vol. 13, June, pp. 95–103). The application of special welding processes such as submerged arc, metallic arc, gas welding, stud welding, and resistance welding to boilermaking and pipelines is described. Pressure vessels are welded satisfactorily by the submerged-arc process using a Union-melt plant. Pipes are joined by the metallic arc with an oxy-acetylene base run or with a backing ring, and X-rays are used for the non-destructive examination of the welds. Studs are welded instead of drilling, tapping, and screwing.—U. E.

Some Aspects of Metallic Arc Welding of Sheet Metal. A. G. Thompson. (Sheet Metal Industries, 1950, vol. 27, Oct., pp. 879–883). By 'sheet metal,' the author means material ⅛ in. thick or less, and he gives a brief outline of the types of electrode, equipment, and power requirements involved in this class of work. Jigging, the fitting-up of jobs before welding, and the manipulation of butt, corner, fillet, lap, and edge welds are discussed.—P. M. C.

The Application of New Automatic Arc Welding Processes. M. Komers and H. Krug. (Schweissen und Schneiden, 1950, vol. 2, June, pp. 118–124). A number of automatic arc welding processes as developed in America and England are described. The Kaell process (Kjellberg) uses a double electrode and a three-phase current. In the Fusarc process the electrode consists of two coiled wires with the flux pressed into them. In the Elin process the electrode is formed in an automatic machine into which is fed a bare wire and two channel-like lines of material to form the coating. The Ellira process (submerged arc) uses a bare rod which is coated at the weld joint with a fluxing powder. The Heliarc welding process is compared with the Arcatom process.—R. A. R.

The Control of Distortion in Arc Welding. R. G. Braithwaite. (Transactions of the Institute of Welding, 1950, vol. 13, Apr., pp. 64–72). The author describes methods of controlling distortion in the arc welding of mild steel for structural assemblies. With complex structures it is difficult to balance welding, and care should be taken to distribute the welding so that the centre of gravity of the welds coincides with the centre of gravity of the completed article. Second and subsequent welds are commenced a run length away from the finished weld and the weld laid to join it. An example is given of this welding procedure for welding up box sections, 12 ft. long of $\frac{3}{16}$-in. plate, for the ends of floating bridge girders.—U. E.

Shrinkage Distortion in Welding. W. Spraragen and W. G. Ettinger. (Welding Journal, 1950, vol. 29, June, pp. 292s–294s; July, pp. 323s–335s). The information in the literature on shrinkage distortion is condensed and grouped under the different factors affecting it and the literature is also reviewed. There are 33 references.—U. E.

The Aircomatic Welding Process. A. Muller, G. J. Gibson, and E. H. Roper. (Welding Journal, 1950, vol. 29, June, pp. 458–482). Fundamentals of metal-arc transfer in inert-gas-shielded arc welding are discussed. A new welding process has been developed in which a consuming bare electrode wire is used. The arc is shielded by an inert monatomic gas flow. Welding can be performed in all positions using the manual method. Welding speeds are faster and the arc is visible at all times, as no flux is used. No slag cleaning is required. The process has been accepted for aluminium pressure vessel fabrication and it can also be applied to austenitic-type stainless steels. Overlays of aluminium bronze on steel, copper, cast iron, and manganese bronze are sound and are bonded securely.—U. E.

Contact Arc Welding. P. C. van der Willigen. (Schweissen und Schneiden, 1950, vol. 2, Oct., pp. 270–278). After discussing the absorption of oxygen and nitrogen by welds made with ordinary coated electrodes, the 'contact' process of electric welding is described. For this process it is necessary for the coating to be thicker and to contain in powder form 20 to 40% of the metal which is normally in the core. This powder increases the conductivity of the coating which

accelerates the beginning of deposition. The process gives deeper penetration at the centre and less at the sides of the fillet. The application of the process in shipbuilding is discussed.—R. A. R.

A Comparison of Progress in Resistance Welding in Britain and America. W. S. Simmie. (Sheet Metal Industries, 1950, vol. 27, Aug., pp. 723–726). This is a very brief comparison of equipment and methods used in both countries. America has far more facilities for research, because of the greater volume of work. Some of the special multiheaded American machines cannot be used in Britain because of power limitations, but 'quality' spot welding is more widely used in the British automobile industry than in the American. Tip and die maintenance, face-welding, and seam-filling by sprayed zinc instead of solder, are briefly outlined.—P. M. C.

The Automatic Flash Welding Machine. A. G. Galle and C. A. Burton. (Welding, 1950, vol. 18, Oct., pp. 437–441; Nov., pp. 481–486). A definition is given of the principles of operation of flash-welding plant and of latest design developments. The length of the periphery of the weld area affects the welding data considerably. It is shown that with increase in length of weld-area periphery and flashing current, a decrease of flashing time can be obtained. Methods for flash-welding tubular forms are described. Correct and incorrect methods for current distribution when welding large sections are illustrated.—U. E.

Electrically Welded Tubing—Its Manufacture, Properties and Applications. W. G. Clewlow. (Transactions of the Institute of Welding, 1950, vol. 13, Aug., pp. 122–127). Mild-steel strip in coil form is machine-welded, the operation proceeding in three steps, *i.e.*, forming, welding, and sizing of the tubes. As the strip enters the forming section, it is first sheared to give the correct width with clean-cut edges and then proceeds through stands of rolls which gradually fold it longitudinally to a **U**-shape and ultimately to the round-butted, open-joint tube. As the tube enters the welding throat, current is forced across the seam, instantly making the weld. It then passes through clusters of rolls which size and straighten the tubes. Microscopical examinations of weld cross-sections are carried out.—W. E.

Recommendations for the Metal Arc Welding of Butt Welds in Steel Pipelines for Power Plant. (Transactions of the Institute of Welding, 1950, vol. 13, June, pp. 46r–46r). Recommendations are given which are applicable to butt welds in pipelines of wall thicknesses from 8 S.W.G. and of diameters exceeding 2 in. By these methods, pipelines varying from these limits up to 13 in. in outside dia. with a wall thickness of 1¼ in. have been successfully welded for working pressures up to 2000 lb./sq. mm. at a working temperature of 540° C. Butt welds in piping of similar sizes and under similar conditions have also been welded by the oxy-acetylene process. The latter process was found to be more suitable for smaller pipes up to approx. 4 in. outside dia. with up to ⅜ in. wall.—U. E.

Operation of New 16 in. Electric-Weld Pipe Mill. C. W. Morehead. (Iron and Steel Engineer, 1950, vol. 27, Dec., pp. 111–115). This paper gives a description of the new electric weld pipe mill recently installed at Page-Hersey Tubes Ltd., Welland, Canada. Seamless, submerged arc welding and electric resistance welding were considered and the reasons for selecting the latter type of mill are given. Information is also given on the size of buildings available and on the construction of the foundations and floors. A description is given of the mill including the handling equipment, roller leveller, flying shears, and the shot blasting. This last operation provides a clean area for the welding electrodes to make contact. The forming mill, the welding unit, and the hydraulic expansion and testing machine are also described. General shop and stockyard facilities are enumerated and production capacities given.—M. D. J. B.

The Production of Chains by Electric Resistance Welding. W. Püngel. (Schweissen und Schneiden, 1950, vol. 2, Aug., pp. 216–220). The advantages of resistance welding as applied to the welding of chains used in the mining industry are discussed. Alloyed steel chains welded in this way have a strength of 70 kg./sq. mm.—U. E.

Welding in Railway Engineering. A. Matting. (Instituto de la Soldadura, 1950, Publication No. 12, pp. 1–59). [In Spanish]. The author gave a series of lectures to the Spanish Institute of Welding on the following subjects: (1) The technique of welding in railway engineering; (2) welding in steam locomotives; (3) welding of copper fireboxes and highly stressed parts; and (4) welding of points and superstructures, with some notes on testing and personnel. In these four lectures, the following subjects are discussed: The fatigue strength of joints in relation to the type of weld and the internal homogeneity of the weld, and some fundamental calculations of joints; various types of weld on steam locomotives, including boiler stays, fireboxes, smoke-boxes, and frames; gas welding of copper parts; and the welding of coaches, wagons, and crossings.—R. S.

Static Testing and Design of Spot-Welded Connections under Shear Stress. H. Zschokke and R. Montandon. (Schweizer Archiv, 1950, vol. 16, Sept., pp. 257–271). The breaking load of a spot-welded test piece depends not only on the diameter of the weld but also on the design of the test piece, because the dimensions of the plates joined and their overlap determine the mode of fracture. Other important factors are the effect of the welding heat and the size of the heat-affected zone. Provided the overlap is sufficient to prevent the weld tearing through the end of one plate, four types of fracture can be obtained, depending on the ratio of weld diameter to plate width. With narrow plates, the fracture occurs in the plate, either at the weld or remote from the weld according to whether the welding heat softens or hardens the material. With wide plates the weld shears across. At an intermediate critical width, the weld pulls right out of one or both plates. A similar behaviour is found when wide plates are joined by a row of spot welds, except that the last type of fracture seldom occurs. The most economical design is obtained by so spacing the welds that the plate and weld fractures are equally likely to occur. Tests on single spot welds in single and double shear and on plates joined by a row of spot welds showed that the critical spacing for the welds in the latter case was slightly less than the critical width in the former. From these tests, the best dimensions for weld diameter, overlap, plate width for single-weld test pieces, and weld spacing for a row of welds, are determined for plates from 0·5 to 4 mm. thick in the following materials: Deep-drawing steel, 18/8 chromium–nickel steel, soft aluminium, and hard aluminium–silicon–magnesium alloy.

H. R. M.

A Critical Examination of Certain Martensitic Hardfacing Electrodes. E. Bishop. (Welding, 1950, vol. 18, July, pp. 290–298; Aug., pp. 345–348). A number of low-alloy hard-facing deposits were made on mild steel (0·2% C). Hardness increased with increasing carbon content, but wide discrepancies were observed due to the different proportions of alloying elements, notably chromium and molybdenum, in the deposits. The effects of base metal admixtures, size of deposit, thickness, and preheat conditions have been investigated. Thus, thermal effects of preheating and of building-up thicker deposits usually result in a degree of softening. The microstructures of the different weld metals are shown.—U. E.

Effect of Welding on Pressure-Vessel Steels. A. F. Scotchbrook, L. Eriv, R. D. Stout, and B. G. Johnston. (Transactions of the American Society of Mechanical Engineers, 1950, vol. 72, July, pp. 539–548). The paper presents the results of Lehigh slow notched-bend tests to determine the effects of welding on as-received and prestrained plate. It also discusses the effects of: (*a*) Different heat inputs in welding; (*b*) plate thickness; (*c*) carbon content; (*d*) deoxidation practice, and (*e*) heat-treatment after welding. The conclusions are: (1) Welding appreciably increases the notch-sensitivity of the material; the increase could not be predicted from the transition temperature of the unwelded plate. (2) Welding prestrained material resulted in a slightly higher transition-temperature level than welding unstrained plate. (3) Welding raises the transition temperature of thick plate more than that of thin plate. (4) The level of transition temperature was apparently a function of carbon content and deoxidation practice. (5) Heat-treatment at 1150° F. after welding greatly improved the material affected by the weld. (6) A 500° F. post-heat improved strained and welded material but not unstrained welded material.—D. H.

Use of Electric Welding in a 250-Ton Horizontal Press. (Tecnica e Industria, 1950, vol. 28, May, p. 498). [In Spanish]. A new 250-ton horizontal press built of welded plates is described. It replaced an old 80–100-ton cast-iron press. Dimensions of the new press are: Length 8–10 m., width 2·7 m., and height 2·7 m. The weight of the welded parts was 8 tons. Murex "Fastex 5" electrodes were used.—R. S.

Assembly Time on Terne Plate Tanks Cut by Forty Per Cent. R. D. Wasserman. (Steel, 1950, vol. 127, July 31, pp. 73–75). It is stated that a new welding rod, a $\frac{3}{32}$-in. 'Steel-Tectic' wire, produces considerable savings in the welding of terne plate or lead-covered steel. The inherent characteristics of the electrode cause each successive layer of slag to float to the top, so that all impurities can be chipped away after the last pass.—A. M. F.

Castings and Plate Combined for Fabrication Economy. O. Blodgett. (Iron Age, 1950, vol. 166, Sept. 7, pp. 110–111). The Falk Corp. of Milwaukee obtain maximum economy in large weldments by the use of both steel castings and plate in heavy machinery structures. Large castings are usually heated locally while welding to minimize the possibility of cracking, and lime–ferritic electrodes are used for the first one or two passes.—A. M. F.

Maintenance by Welding. A Survey. M. Riddihough. (Transactions of the Indian Institute of Metals, 1949, vol. 3, pp. 347–357). The paper surveys the present position of hard-facing (the welding of a hard wear-resistant surface on to components). The author regards this as a valuable method of increasing efficiency and reducing maintenance costs. The structures of a number of alloys specially developed for this purpose are given, and recommendations for their use for general engineering purposes in mining, civil, mechanical, power, food, and chemical engineering are indicated. The technique of welding is outlined.—D. H.

A Gaseous Flux. B. Liebesmann. (Schweisstechnik, 1950, vol. 4, Feb., pp. 18–23). The flux consists of borax dissolved in either ethyl-, methyl-, or butyl-alcohol. The liquid evaporates in the welding flame. A certain amount of organic matter is added to prevent hydrolysis, a temperature decrease, and crystallization of the boric acid. Welding is carried out in the ordinary way giving a clean surface. A higher weld strength is obtained with the gaseous flux as compared with ordinary paste flux.—U. E.

Precision Rings Hot Pressure Welded. G. C. Close. (Steel, 1950, vol. 127, Aug. 14, pp. 88–89, 111–112). C. C. Slate and Co., of Los Angeles, are producing close-tolerance rings and other parts by hot pressure welding. The advantages claimed over other types of welding are: (1) Adaptability of the process to weld high and low carbon steels. (2) Smoothness and uniformity of the completed weld. (3) Relatively low cost in repetitive work. (4) Maintenance of the metallurgical characteristics of the base metal. In the process, the surfaces to be joined are carefully ground or machined to fit perfectly, they are pressed together to exclude air and the possibility of oxide formation, heated to a plastic state, and then upsetting pressure is applied. After welding, the rings to be machined are flash heated to a redness, and forced down over a conical mandrel to give the circular shape.—A. M. F.

Autogenous Pressure Welding. O. Renner and L. Wolff. (Schweissen und Schneiden, 1950, vol. 2, Nov., pp. 283–293). In this process the two pieces to be welded are pressed together at room temperature and then heated to a temperature below the melting point of the alloy by means of two burners. Recrystallization occurs which will give a joint showing physical properties similar to those of high-quality gas welds. Pressure-welding machines for welding tubes and round bars with cross-sectional areas up to 45,000 sq. mm. are described. U. E.

Gas Welding of Plates up to 24-mm. Thick Using Small Burners. The Application of Double-V Welds in the Manual Welding Process and Its Importance. H. Melhardt. (Schweisstechnik, 1950, vol. 4, June, pp. 61–72). Gas welding of 24-mm. thick plates for pressure vessels is discussed in detail giving illustrations of the positions of flame and rod. There are ten references.—U. E.

How to Fusion-Weld Cast Iron. F. C. Geibig. (Welding Journal, 1950, vol. 29, July, pp. 583–587). The repair of grey cast-iron parts by fusion welding is described. Illustrations are given showing the position of the rod and blowpipe in various cases, and how to build a 'welding furnace.'—U. E.

Applications for Helium in Inert-Arc Welding. M. J. Conway. (Welding Journal, 1950, vol. 29, July, pp. 533–536). The paper gives a historical review and stresses the advantages of the application of helium in inert-gas-shielded arc welding. U. E.

Some Aspects of Fusion Welding for the Chemical and Food Producing Industries. F. Jukes. (Transactions of the Institute of Welding, 1950, vol. 13, June, pp. 79–86). The fusion welding of stainless steels is discussed. Ferritic steels can be fusion welded but weldability is poor. Special care must be taken owing to their air-hardening tendency. Preheating and post-heating are therefore necessary. Weldability of austenitic steels is excellent, using either the fusion or resistance welding process. Straight chromium and austenitic nickel–chromium steels cannot be satisfactorily welded in the smith's hearth. Examples are given of welding fabricated products for the chemical and food processing industries.—U. E.

The Argonarc Welding of Stainless Steel Sheet. J. F. Lancaster. (Transactions of the Institute of Welding, 1950, vol. 13, Aug., pp. 111–121). Argon-arc welding as applied to thin stainless steel sheet is discussed. Laboratory tests showed that the quality of argonarc welds was rather higher than the previously accepted standard. The application of Argonarc welding to jobs where some additional economic advantage was gained, the use of more efficient gas economizers, dilution of argon with less expensive gases, and the development of mechanical methods are described.—U. E.

How to Weld Corrosion Resistant Materials. W. G. Scherer. (Materials and Methods, 1950, vol. 32, Aug., pp. 60–61). By using correct procedures, welds that are no more susceptible to corrosion than the parent metal can be made in most corrosion-resistant materials. The author briefly describes the cleaning and edge bevelling methods, and the compositions of filler rods used in the welding of nickel, Monel, Inconel, copper, silicon bronzes, and stainless steels.—P. M. C.

Stainless Can be Brazed for 2000° F. Service. R. L. Peaslee and W. M. Boam. (Iron Age, 1950, vol. 166, Sept. 28, pp. 74–77; Oct. 5, pp. 84–87). Exhaustive tests show that joints brazed in a dry hydrogen atmosphere with a brazing alloy of "Colmony No. 6" and S590 as a base metal have suitable physical properties for 2000° F. service. Tensile strength, yield strength, and proportional limit are generally as high as the physical properties of the base metal at high temperatures. Oxidation resistance is excellent. The brazing alloy is of nickel–chromium base and is used in powder form; mixed with an acrylic resin it can be held in position on the underside of an article right up to the melting point of the alloy. The solidus temperature of the brazing alloy is only 1850° F., but in the joint a new alloy is formed giving strength at 2000° F.—A. M. F.

Copper Brazing of Case Hardening Steel. S. C. Churchill. (Machinery, 1950, vol. 76, June 22, pp. 884–889). Investigations on the effect of high brazing temperature on steel subsequently refined and hardened are reported. Single-notch Izod specimens of British Standard S14 steel (C 0·10–0–18%, Si 0·30% max., Mn 0·90% max.) were used. One surprising result was that of two specimens *C* and *D*, simultaneously carburized and air-cooled, and then treated for 60 min. at 1120° C., *C* in burnt coal gas and *D* in hydrogen, the depths of decarburization were 0·015 in. for *C* and 0·025 in. for *D*. Normalizing between brazing and subsequent carburizing, refining, and hardening did not result in any improvement in the impact properties. Tests were made to determine the effect of sodium cyanide on the copper of a brazed joint. No serious attack could be detected and no effect was observed beyond a maximum depth of 0·005 in. R. A. R.

Underbead Cracking of Welds Cathodically Charged with Hydrogen. M. W. Mallett and P. J. Rieppel. (Welding Journal, 1950, vol. 29, July, pp. 343s–347s). Underbead cracking has been studied on heat-treated manganese–molybdenum and a few 18/8 stainless-steel plates. It is shown that it does not occur in welds free from material undergoing austenite–martensite transformation. A direct correlation exists between the amount of austenite retained at the time of cathodic charging with hydrogen, and the amount of underbead cracking. The effects of (*a*) retained austenite and (*b*) concentration of absorbed hydrogen have been isolated. They do not produce underbead cracking individually.—U. E.

A New Instrument for Measuring the Thickness of Fillet and Butt Welds. (Schweisstechnik, 1950, vol. 4, Apr., pp. 38–39). A dial-gauge instrument, developed by Gebr. Böhler and Co., A.G., Vienna, which gives a direct reading in millimetres of the thickness of fillet and butt welds is described and illustrated.—R. A. R.

Fatigue Strength of Welded Butt Joints. (Welding Journal, 1950, vol. 29, Aug., pp. 404s–408s). Fatigue tests were carried out on $\frac{7}{8}$-in. carbon steel plates to A.S.T.M. specification A7.

All welding was done manually with E6010 electrodes giving double **U**-groove welds with zero root opening and partial joint penetration. Tests results are also given in tables and figures for ½-in. specimens and with single **V**-groove welded butt joints welded both sides with complete joint penetration when fatigue tested in a zero-to-tension stress cycle at room temp.—U. E.

The Value and Scope of X-Ray Testing for Welded Seams. E. Uhlir. (Schweisstechnik, 1950, vol. 4, Sept., pp. 98–101). A thorough knowledge of prevailing stress conditions is necessary before evaluating X-ray data. It is shown that an X-ray investigation carried out on 5–20% of the total weld seam will give sufficient data on the general condition of the whole of the weld.—U. E.

MACHINING AND MACHINABILITY

Microscope Method Expedites Machinability Tests. T. Badger. (Iron Age, 1950, vol. 166, Oct. 5, pp. 79–83). A method developed by the Westinghouse Electric Corp. gives accurate and rapid evaluation of tool life in any cutting application. An important part of the procedure is the measurement of tool wear microscopically. The definition of machinability is taken as the ratio of cutting speeds with uniform tool life compared with a standard material. This ratio is most accurately determined by comparing the curves of speed against tool life of the tested and standard material.
A. M. F.

A Dimensional Analysis of Metal Cutting. D. C. Drucker and H. Ekstein. (Journal of Applied Physics, 1950, vol. 21, Feb., pp. 104–107). Dimensional analysis is used in a study of the behaviour of metal when it is cut. Present theories are described and some additional significant variables are found. The analysis provides a basis for the interpretation of known experimental results and is intended to serve as a guide for future experimental and theoretical investigations.—J. P. S.

Correlation of Plastic Deformation during Metal Cutting with Tensile Properties of the Work Material. J. T. Lapsley, jun., R. C. Grassi, and E. G. Thomsen. (Transactions of the American Society of Mechanical Engineers, 1950, vol. 72, Oct., pp. 979–986). An experimental correlation of plastic deformation occurring during metal cutting with the plastic deformation in tension of the work material, and an analysis permitting comparison of these two states of strain are presented. Orthogonal cutting of seamless steel tubing was employed for feeds of 0·0025–0·0085 in. per revolution, and positive rake angles of 25–45°. Deformation and cutting forces were obtained from chip measurement and from a tool dynamometer employing resistance strain gauges. The agreement obtained indicates that the tensile properties of the work material may offer a useful index to metal-cutting performance.—D. H.

The Industrial Diamond—Applications in Machining and Results Obtained. (Maquinas e Metais, 1950, May, p. 25). [In French]. Great hardness, homogeneity, and surface polish of diamond guarantee good surface finish and precision in bearings, pistons, capillary tubes, and plastics. The applications discussed include: Counter-pivots; inscribing tools; profilometer feelers; microscope lenses; and hardness testing machines.—R. S.

Gear Shaving. (Maquinas e Metais, 1950, June, pp. 27–30). [In Italian]. The advantages of gear shaving are: Production of silent gears; low cost; precision equal to that of normal machining methods; and minimum amount of error in section and eccentricity. The use of this method with heat-treated, case-hardening, air-hardening, and nitriding steels is described. Finally, the characteristics of the Vianini shaver are briefly described.—R. S.

Surface Finish and the Designer. R. P. Trowbridge. (Product Engineering, 1950, vol. 21, Sept., pp. 122–127). The author gives some of the basic considerations that should be recognized by the designer before placing controls on the surface finish of a part. Details of surface measuring instruments and methods such as the stylus type, taper sectioning, optical and geometric comparison are given, and production methods for specified finishes are compared in a table.
A. M. F.

Babcock and Wilcox Limited, Renfrew: Engineering and Boiler Construction. (Iron and Coal Trades Review, 1950, vol. 161, Sept. 22, pp. 452–454, 461). The works of Babcock and Wilcox, Ltd., specializes in the development and production of all types of steam-raising equipment. Brief descriptions of the plant, and the work of the various departments are presented, special attention being given to the machine shops, iron foundry, section shop, and research and development department.—G. F.

Which Coolant? L. Suhadolnik. (Steel, 1950, vol. 127, Sept. 25, pp. 77–80). A new technique for deciding which coolant to use in general all-round machining involves the measurement of the effectiveness of an emulsified oil by determining the loss of weight in a tool after a predetermined number of work pieces are machined.—A. M. F.

CLEANING AND PICKLING

Mill Roll Blasting Reduces Operating Costs. G. D. Dill. (Steel, 1950, vol. 127, Oct. 2, pp. 98–102). This article gives descriptions of shot-blasting cabinets made by the American Wheelabrator and Equipment Corporation for etching rolls. The most important part of the equipment is a 25-h.p. motor which drives a wheel at 2250 r.p.m. to throw 400 lb./min. of abrasive to secure a blast pattern 30 in. long and 3 in. wide. The spent abrasive is separated to remove undersized particles and is automatically returned to the feeding hopper. The cabinet is kept at a negative pressure to prevent dust escaping and the total cycle time for a roll can be 8 minutes.—A. M. F.

Modern Metal Finishing—A Science. H. Shaw. (Iron Age, 1950, vol. 166, Oct. 5, pp. 90–93). A description is given of a modern cleaning and finishing plant at the Coleman Co., Inc. Conveyors through controlled atmosphere buildings and automatic processing cycles produce consistently finished parts.—A. M. F.

Some Modern Methods of Surface Preparation before Plating. W. A. Corse. (Plating, 1950, vol. 37, Apr., pp. 375–377, 383). Three methods are described. The first employs machines in which abrasive belts, mounted vertically, prepare the surface of flat steel strip. There may be several machines in tandem, the grit of the belts being progressively finer, so that the strip is ready for forming and then plating after cleaning. The second method employs back-stand belt polishing and the third uses brush-backed sander heads. The latter are wheels 12 in. in dia., 2–4 in. wide, having 32 brushes mounted around the periphery. Strips of coated abrasives protrude from the inside of the wheel in front of each brush, projecting slightly beyond the brush tips. The head is mounted on a polishing lathe. The brushes provide a flexible support for the coated abrasive as it contacts the work.—J. P.

Pickling Tanks: Modern Developments in Construction. V. Evans. (Iron and Steel, 1950, vol. 23, Apr., pp. 116–120). The author discusses the design and construction of modern pickling tanks. In general these consist of: (1) An outer tank, which may be built of brickwork, concrete, or mild steel; (2) an impervious membrane lining, usually of chemically resistant asphalt or chemical grade sheet rubber; and (3) an inner lining of corrosion-resistant bricks set in corrosion-resistant cement. The cements normally used are silicate cements, sulphur cements, or cements based on synthetic resins. The chief types of chemical conditions met with in pickling practice are taken into account in discussing the selection of material to be used.—G. F.

Pickling and Pickling Inhibition. A. Douty. (Plating, 1950, vol. 37, Mar., pp. 269–271). The mechanism of pickling of steel and the effects of inhibitors are briefly discussed. Inhibitors function by forming a layer on the metal which impedes the passage of hydrogen ions. Although inhibitors reduce the amount of hydrogen evolution, it has been shown that they do not in all instances reduce the amount of hydrogen embrittlement.—J. P.

The Mode of Action of Pickling Inhibitors. F. Willems. (Werkstoff und Korrosion, 1950, vol. 1, June–July, pp. 239–244). The extent and nature of the attack of pickling solutions containing one each of seven different (unspecified) inhibitors on iron specimens at room temperature in experiments of long duration (up to 90 days) is reported.—O. H. G.

Urea-Formaldehyde Pickling Inhibitors. (Electroplating, 1950, vol. 3, Nov., p. 565). The Pennsylvania Salt Manufacturing Co. patented the preparation of pickling inhibitors by the condensation of urea or thiourea with various aldehydes. The results quoted for formaldehyde-, paraldehyde-, propionaldehyde-, butyraldehyde-, benzaldehyde-, and cro-

tonaldehyde-ureas indicate inhibiting efficiencies of the order of 80–99·9%, though it should be noted that the inhibitors were present at the very high concentration of 0·5% by weight. It is claimed that the urea-aldehyde condensation products are very stable in hot sulphuric acid.—J. P.

How to Reduce Pickling Brittleness in Stainless Steel. C. A. Zapffe. (Materials and Methods, 1950, vol. 32, Nov., pp. 74–77). Bend test results are quoted, which indicate that hydrogen embrittlement is increased by adding an inhibitor to an acid pickling solution. Only one commercial reagent (Rodine 250) has so far been developed which minimizes embrittlement. The addition of wetting agents and foaming compounds to acid pickling baths, and the use of hydride baths, does not noticeably affect embrittlement. The removal of hydrogen by mild heating, and the phenomena of ageing and recovery are briefly discussed.—P. M. C.

Notes on the Selection and Handling of Trichlorethylene Degreasing Plants. (Electroplating, 1950, vol. 3, Nov., pp. 560–564; Dec., pp. 614–617). The advantages and disadvantages of the vapour, liquor-vapour, and multi-liquor types of trichlorethylene plant are discussed. It is recommended that care should be taken in putting articles into and removing them from the tanks in order to avoid loss of solvent by displacement and drag-out of the heavy vapour.—J. P.

A Survey of the Chemical Aspects of some Degreasing Processes Used for Metal Finishing. J. G. Baker. (Sheet Metal Industries, 1950, vol. 27, Aug., pp. 737–742). The importance of knowing the previous history of an article, before deciding what degreasing method is required, is discussed. Trichlorethylene methods, which involve no chemical attack, are described in detail, and reference is also made to the use of alkaline solutions. The use of weak acids and electrolytic methods, for the removal of surface tarnish by chemical action, are necessary if the article is to be plated.
P. M. C.

The Sodium Hydride Process and Its Application to the Cleaning of Moulds for the Glass Industry. N. L. Evans. (Journal of the Society of Glass Technology, 1950, vol. 34, Apr., pp. 55–59). The rapid cleaning and descaling of metal moulds by sodium hydride treatment is described. The hydride is used in solution in molten anhydrous caustic soda, at a concentration of 1 to 2%. The operating temperature of the bath is 350 to 370° C. Typical descaling reactions are: $4NaH + Fe_3O_4 = 3Fe + 4NaOH$; $NaH + CuO = Cu + NaOH$; and $NaH + Cr_2O_3 = 2CrO + NaOH$. Common metallic oxides are reduced completely, with the exception of chromic oxide which is loosely adherent. When the temperature of the bath is reached, the scale on the metal surface is reduced in less than two minutes. No serious corrosion problems are associated with the process and it is impossible to 'over-pickle.' The construction and operation of the hydride bath and the hydride generator are illustrated.—E. J. D. S.

Salt Bath Cleaning of Gray Iron Castings. R. H. Herrmann. (Foundry, 1950, vol. 78, Aug., pp. 90–91, 204–205). An automatic and continuous process for normalizing and cleaning grey-iron castings at an automobile plant is described.
E. J. D. S.

Practical Electropolishing of Stainless Steel. F. G. Brune. (Metal Finishing, 1950, vol. 48, Oct., pp. 57–62, 112). The tests carried out on electropolishing stainless steel articles in the sulphuric–phosphoric acid bath at the Electric Auto-Lite Co., before putting the process on a production basis, are described. These involved determining the influence of dissolved iron in the bath and of the physical condition of the steel being processed. With the co-operation of the steel-makers, it was possible to eliminate defects which arose as a result of the various mill-finishing treatments.—J. P.

Electrolytic Polishing of Metals. Technical and Economic Advantages. J. J. Balestrini and E. Cusi. (Tecnica e Industria, 1950, vol. 28, June, pp. 600–602). [In Spanish]. It is stated that electrolytic polishing lowers polishing costs 30%. The method is examined on the basis of the current-density/voltage diagram which illustrates the effects of variations in current on the anodic corrosion. Extremely careful control of temperature, current density, and the physico-chemical state of the electrolyte are required. The main advantage of the process is the elimination of labour required for mechanical polishing, especially for awkward shapes. Risk of burning is avoided. Electrolytic polishing is used for preparing surfaces for plating.—R. S.

The Metal under the Plate. H. E. Boyer. (American Electroplaters' Society: Products Finishing, 1950, vol. 14, Sept., pp. 14–22). The effect of carbon content on the ease with which oxide films can be removed from various types of steel and cast iron, and adherent electrodeposits obtained are discussed in an arbitrary manner. No experimental evidence is adduced in support of the statements made.—J. P.

Swirl Method for the Evaluation of Metal Cleaners. R. H. Tiers. (Metal Finishing, 1950, vol. 48, Sept., pp. 56–60). A method for comparing the efficiency of aqueous alkaline cleaners is described. Standard-sized panels of steel are uniformly coated with a fixed weight of a contaminant consisting of a mixture of lubricating oil, cup grease, powdered asbestos, charcoal bone powder, tall oil, and ceresin wax or of lubricating oil, cup grease, asbestos, charcoal, coal tar, and paraffin, and then rotated in a horizontal plane in the solution being examined. A baffle in the container ensures good mechanical action of the cleaning solution. The percentage of soil removed is determined by weighing. Providing all conditions such as temperature, composition, speed of rotation, etc., are rigidly standardized, the test is reproducible and satisfactorily compares different cleaners. The conditions to be employed for comparing one mild alkaline cleaner with another should be less drastic than those for comparing strong cleaners.—J. P.

Metal Colouring and Bronzing. C. Harris. (Metal Industry, 1950, vol. 77, Dec. 22, pp. 295–298). Colouring for ornamentation, and bronzing for protection are effected by heat, chemical, and electrolytic methods. The surface preparation before the above treatments is of great importance, and is described in detail. Typical solutions for sand and scale removal from steel, for the treatment of stainless steels, and for scale removal from copper, brasses, and bronzes are given. Grease removal, satin finishing, and 'relieving' are also described.—P. M. C.

Mechanical Finishing of Metals for Decorative Purposes. J. B. Campbell. (Materials and Methods, 1950, vol. 32, Nov., pp. 81–96). This very comprehensive article deals with the following mechanical processes: Polishing, buffing, brushing, blasting, tumbling, and burnishing. These 'unit operations' are evaluated as to advantages, limitations, and control of process variables. In addition, specific finishing procedures are outlined for each of the major groups of alloys.—P. M. C.

The Jenolite Rust-Removing Process. (Engineering, 1950, vol. 170, Dec. 22, p. 532). A brief description is given of a process for removing rust and scale from steel and, at the same time, imparting a protective 'phosphated' surface to the metal which provides a key for subsequent painting. Depending on the degree of rust, the articles are immersed in the liquid for times varying from 2 to 15 min. No further treatment is required and drying may be effected by wiping or by directing compressed air on the article depending on its size. Jenolite may be applied to large structures by means of a paint brush and subsequently painted as soon as dry. The material is produced by Jenolite, Ltd., London.—M. D. J. B.

Washouts of High Pressure Steam Turbines. W. K. Dumbaugh. (Iron and Steel Engineer, 1950, vol. 27, Sept., pp. 49–55). The formation of blade deposits is considered together with the methods of cleaning these by turbine washing with initially wet steam. Details of the three high-pressure turbines of the Weirton Steel Co. are given together with their efficiencies before and after washing out. Turbine availability has gone up to over 4000 operating hours from under 2000. Detailed information concerning the washing is given in tabular form. Brief information is also given on the general layout and procedure adopted in turbine washing.
M. D. J. B.

PROTECTIVE COATINGS

Theory of Rate Processes as a Means of Studying Plating Reactions. D. A. Rogers and A. A. Burr. (Journal of the Electrochemical Society, 1950, vol. 97, Mar., pp. 92–98). The application of absolute reaction rate theory to plating cells has been discussed by Glasstone, Laidler, and Eyring, and suggestions, based on equations adapted from the literature, are made for a method of studying plating cells where current efficiency is less than 100%. Operating data from chromium baths show the applicability of the equations and indicate the possibility of the method for the study of irreversible plating reactions. The effect of sulphate ratio on the plating of chromium has been studied and the results

indicate that the beneficial influence of the sulphate ion arises from a retardation of hydrogen deposition rather than from catalysis of the plating reaction.—J. P.

On the Determination of the Roughness of Metallic Surfaces. C. Wagner. (Journal of the Electrochemical Society, 1950, vol. 97, Mar., pp. 71–74). The true surface area of a solid frequently exceeds its geometrical or apparent area because of a certain roughness. The polarization capacity of an electrode, due to the existence of an electrical double layer at the surface of a metal immersed in an electrolyte, can be assessed readily with the aid of a ballistic galvanometer, which measures the quantity of electricity required to establish a steady state when the potential of an electrode is changed from one value to another. The polarization capacity per unit of apparent area can be considered to be approximately proportional to the roughness of the surface of the electrode. Results obtained with silver electrodes showed that, when a silver chloride surface is reduced electrolytically, the roughness is greater the higher the value of the reducing current and that ageing, which proceeds to completion in a few minutes, reduces the different surfaces to the same order of roughness.—J. P.

Porosity of Electrodeposited Metals. VI. Effect of Surface Structure of the Base Metal on the Permeability and Corrodibility of Deposits. N. Thon, L. Yang, and D. Keleman. (Plating, 1950, vol. 37, Mar., pp. 281–284). The gas permeability of thin layers of nickel and iron deposited on polished stainless steel and copper is greater than that of similar deposits on etched copper. Moreover, thick and therefore essentially impermeable films deposited on the polished metals corrode initially in the atmosphere at a greater rate than similar films deposited on etched surfaces.—J. P.

The Strength and Ductility of Electrodeposited Metals. The Hydraulic Buige Test. T. A. Prater and H. J. Read. (Plating, 1949, vol. 36, Dec., pp. 1221–1226). The determination of tensile strength, elongation, and reduction in area of thin films of electrodeposited metals is almost impossible in conventional testing equipment. The authors describe a test in which a metal film is clamped between two flanges and subjected to hydraulic pressure by forcing oil under the film. The extent of bulging is measured by keeping the top of the dome produced in focus in a microscope fitted with a micrometer movement. The observations necessary during the test are the oil pressure and the height of the dome—two operators are therefore necessary. The method by which a significant-stress/significant-strain curve can be derived from such observations is derived mathematically.—J. P.

Choice of Electrodeposited Coatings. C. H. Sample. (Plating, 1950, vol. 37, May, pp. 482–484). Attention is called to those factors which should be considered in the selection of electrodeposited coatings and the sources of pertinent information are indicated. The rôle of these coatings in corrosion prevention is discussed.—J. P.

Hydrogen Embrittlement in Cadmium and Zinc Electrolytes. C. A. Zapffe and M. E. Haslem. (Plating, 1950, vol. 37, Apr., pp. 366–371). Embrittlement through hydrogen absorption by the cathode is measured in terms of the bend angle sustained by plated wires before fracturing. Mild steel is much less embrittled by plating in cadmium and zinc baths than by cathodic pickling, but stainless steel (AISI 440-C type) is severely embrittled by all cadmium and zinc cyanide baths to the extent of exceeding in certain cases the damage caused by cathodic pickling. The effect appears to be independent of normal variations in composition or of the numerous reagents added as brighteners. Acid zinc solutions are much less severely embrittling, confirming a similar comparison drawn in earlier work with copper plating.—J. P.

Studies on the Structure of Hard Chromium Plate. C. A. Snavely and C. L. Faust. (Journal of the Electrochemical Society, 1950, vol. 97, Mar., pp. 99–108). The changes in microstructure which take place during the annealing of chromium plate are illustrated by a series of photomicrographs. Recrystallization can be effected between 300° and 500° C. Loss of hardness is concurrent with recrystallization. A slight loss of hardness at lower annealing temperatures is ascribed to recovery from internal stress. The amount of metal to be deposited before a growing layer assumes its normal preferred orientation is greater with rough than with smooth base metal surfaces. Etched cross-sections of metal as plated reveal certain striations whose width corresponds to a time cycle of some 15 min. The cause of this periodicity is unknown. The results of hydrogen extraction tests are given for temperatures up to 650° C. X-ray and electron diffraction studies show that heating to above the temperature range at which the metal softens does not destroy the normal (111) preferred orientation. Examination of the cross-sections of the annealed specimens indicated that a major portion, if not all, of the oxide visible after annealing occupied approximately the same positions as the original inclusions and it is therefore assumed to have originated in these positions. This tends to disprove the 'dispersed oxide' theory of the hardness of chromium plate and to show that softening is related to recrystallization and grain growth.—J. P.

Protective Coatings Obtained by Chromium Diffusion. W. Tofaute and W. Kock. (Instituto del Hierro y del Acero, 1950, vol. 3, July–Sept., pp. 187–194). [In Spanish]. The use of granular metallic chromium heated to the diffusion temperature in contact with the parts to be chromized does not produce a uniform coating. As regards liquid metallic baths, the melting point of the chromium alloys used is very high. Gaseous chromium has far too low a pressure to give satisfactory results.

Chromium salts react with metallic iron ($CrCl_2 + Fe = FeCl_2 + Cr$) to diffuse metallic chromium into the surface of the parts. The effect of silicon on this reaction is examined. Tests were carried out, using pure chromium protochloride. The ratio of $CrCl_3$ to $CrCl_2$ was varied and plotted against the thickness of coating obtained after 4 hr. chromizing at 1100° C. on mild steel and on 5% Si steel. The higher diffusion rate of the ferritic structure of the silicon steel produces a thicker coating than is obtained with the austenitic structure of the mild steel. At the diffusion temperature carbon concentrates in the chromium-rich zones and impedes the diffusion of chromium and the formation of a chromium layer of sufficient thickness. The relationships between the carbon content of the base metal and that of the chromized layer obtained under vacuum are discussed. The effects of changes in bath composition and the vacuum gaseous chromizing method are described. Comparative corrosion test results for 18/8, 17% Cr steel and three chromized specimens in boiling nitric acid (45%), acetic acid (10%), and a boiling sulphuric–nitric mixture are given. Finally, some notes are given on the welding of chromized parts.—R. S.

Self-Regulating Chromium Bath Plates 20 to 80% Faster. A. H. Allen. (Steel, 1950, vol. 127, Oct. 16, pp. 98–99). The United Chromium Inc., New York, has developed a new type of plating solution for increasing the production of existing equipment. The process consists of using chromic acid solutions with mixed and co-operating acid catalyst radicals in automatically controlled concentration, the bath being kept as a continuously saturated solution by an excess of catalyst. The bright plating range is considerably widened and an increase in plating speed is possible.—A. M. F.

The Chromium Diffusion Process. (Product Finishing, 1950, vol. 3, Oct., pp. 32–37). The process developed and worked by Diffusion Alloys, Ltd., New Eltham, for diffusing chromium into steel products to form a chromium-rich alloy on the surface is described. The depth of the alloy, illustrated by photomicrographs, is from 0·0005–0·025 in. and the average chromium content of the layer is 30%. The chromium diffusion is carried out at temperatures between 880° and 1040° C. in boxes packed with a special powder containing a high percentage of finely divided chromium, the period of treatment depending upon the required depth of alloy layer. The physical properties of the layer depend on the steel base. On 0·1–0·35% carbon steels the chromized layer is very ductile and can easily be cold worked. Chromized sheets can be bent, pressed, and stamped with ease without damage to the alloy layer. On steel of high carbon content, the layer is less ductile, but is very hard and resistant to abrasion. Surfaces of cutting tools and beds and slides, where wear resistance is desired, appear to be instances where the diffusion process may be applied with profit.—J. R.

Unsuitable Iron Bases for Hot Galvanizing. H. Bablik. (Metalloberfläche, 1950, vol. 4, Apr., pp. A49–A53). The failures (especially so-called 'hotspots') which may occur on hot galvanizing unsuitable surfaces are discussed and illustrated by photomicrographs. The hot galvanizing of cast iron is discussed.—O. H. G.

Galvanizing of Steel Sheets: Operational Formulae. J. H.

Mort. (Iron and Steel, 1950, vol. 23, Mar., pp. 74–78; Apr., pp. 125–130). The author derives a number of operational formulæ concerning the galvanizing of steel sheets, which enable accurate forecasts of requirements and results to be made. He deals first with the hot-dip method, and after a brief description of the process, derives throughput formulæ for computing production in terms of both area and weight. Nomograms are also presented. Next the heat balance of the galvanizing bath is considered, and formulæ are given enabling the thermal efficiency to be calculated. The author then discusses the possibilities of electrolytic galvanizing, and gives similar equations for this process; he shows that the heat input per ton is likely to be greater in electrolytic galvanizing than in hot dipping, but a more tenacious coating will result and there will be no dross accretions or flux skimming. A special slide-rule, based on the formulæ, useful to designers and operators of electrolytic plating lines, is described. Finally he deals with corrugations and shows how to correlate depth, pitch, and number of corrugations with the width of flat sheet and the effective and overall widths of corrugated sheet. In each case, typical examples illustrating the application of the formulæ are given.—G. F.

The " Protecta-Tin " Process. (Product Finishing, 1950, vol. 3, Dec., pp. 58–61). The method developed by the Tin Research Institute for treating tinplate, before or after fabrication, to make it resistant to corrosion and sulphur staining is described. The invisible film is produced in a hot bath of sodium hydroxide, trisodium phosphate, sodium dichromate, a wetting agent, and water. A method for ensuring effective filming, and analytical control procedures are dealt with.—J. P.

Electrolytic Tinplate, Its Production and Benefits. S. S. Johnston. (Plating, 1949, vol. 36, Dec., pp. 1233–1235). The operation, production costs, and advantages of continuous electrolytic tinning lines and applications of the electro-tinplate are briefly discussed.—J. P.

An X-Ray Method for Determining Tin Coating Thicknesses on Steel. H. F. Beeghly. (Journal of the Electrochemical Society, 1950, vol. 97, Apr., pp. 152–157). The thickness of tin coatings on steel can be measured rapidly and non-destructively on either side of the sheet by application of a simple X-ray technique. The method is based on the selection of a beam of a wavelength which excites secondary radiation in the steel but not in the tin. The intensity of the resultant secondary radiation is then an inverse function of the thickness of the absorbing layer of tin. The results obtained with the method are reproducible and compare in accuracy with those obtained by stripping by Clarke's method. A unit has been built for the continuous indication and control of tin coating weights on an electrotinning line. It is shown that the principle is applicable to other coatings.—J. P.

Sprayed Metal Coatings for Corrosion Protection. G. Tolley. (Metal Finishing, 1950, vol. 48, Oct., pp. 69–72). The use of zinc, cadmium, and aluminium coatings, applied by spraying, for protection against atmospheric corrosion is discussed. The advantages to be gained from such application and the present development in Britain are illustrated by reference to the work of Hudson and Banfield and to the practices at the new construction at the Abbey Works of the Steel Company of Wales.—J. P.

Corrosion Protection by Spraying. I. C. Fritz. (Werkstoff und Korrosion, 1950, vol. 1, June–July, pp. 261–263). The use of metal-spraying for corrosion protection is reviewed.

O. H. G.

Service Results from Hard Facing. N. D. Berrick. (Commonwealth Engineer, 1950, vol. 38, Aug., pp. 10–12). Results are cited of tests using Cobalide hard-facing alloys on pneumatic chisel bits, pulverizing hammers, well-boring bits, dredger bucket lips, and coal cutter picks. In all cases a very much longer life than that of manganese steel facings was obtained.—R. A. R.

Hardfacing. F. W. Weigel. (Machine Design, 1950, vol. 22, May, pp. 126–128). Mention is made of the application of hardfacing to a worm shaft for a large screw press for vegetable oil, and the hardfacing of a flaking roll weighing over 5000 lb. (24 ft. in dia. × 40 ft. long) covered with a deposit to give a hardness of 52 Rockwell C is described. A list of suitable welding rods is given. Oxy-acetylene torch welding is recommended in preference to arc welding. Importance of design to eliminate cracking hazards is underlined.

T. W. H.

Hardfacing *v.* Abrasion. M. Riddihough. (Welding, 1950, vol. 18, Mar., pp. 109–111). The effect of abrasion upon hard-faced earth-moving equipment is discussed. Special emphasis is laid upon the need for selecting different alloys for work on different soils.—U. E.

Plating and Metal Spraying: Complementary Processes. W. E. Ballard. (Electroplating, 1950, vol. 3, Dec., pp. 600–604). In their present stages of development, plating and metal spraying are complementary rather than competitive processes. Both are of value for decoration, protection against corrosion, and for such engineering applications as the building up of worn or undersized components, but the circumstances in which each should be used differ, as also do the characteristics of the applied metal layer. The similarities and differences between the two processes are restated, and suggestions are advanced which may be of service to both industries.—J. P.

Metal Spraying Pays Off as " Finishing Tool." (Steel, 1950, vol. 127, Aug. 28, pp. 79–82). Metal spraying for finishing can effect economies in two ways, first by stepping up production through its speed and portability of equipment, and secondly by its judicious use in conjunction with paints for which, being porous, it offers a good base. Generally the same finish is obtained from a thinner metallized coating which is painted as a thicker unpainted coating. Which is the more economical depends on local conditions and the nature of the article.—A. M. F.

Conveyors Speed Sash Finishing. W. Rudolph. (Iron Age, 1950, vol. 166, Aug. 31, pp. 56–59). The author describes a new steel frame window finishing plant of the Truscon Steel Co., Youngstown. The plant contains two 1200-ft. monorail conveyors which in a transit time of 100 min. pass through cleaning, bonderizing, painting, and baking units.

A. M. F.

Liquid Enamelling of Cast Iron. P. Tyvaert. (Fonderie, 1949, Dec., pp. 1876–1879). The metal is prepared by annealing (to avoid ' swelling ' after the enamel baking, to degasify and to eliminate carbonaceous matter by combustion), followed by mechanical descaling. This is done by sand-blasting or steel shot blasting, using compressed air or centrifugal force. In enamelling, an anti-oxide fritted mass is deposited to give a hard and porous layer to insulate the surface. Some enamels can be sprayed directly without an intervening layer. Stove box drying at 70° C. or continuous drying is followed by final baking.—R. S.

Butyl Titanate Heat Resisting Paints. (Product Finishing, 1950, vol. 3, June, pp. 39–42). The work of the Division of Industrial Chemistry of the Commonwealth Scientific and Industrial Organization, Australia, in developing heat-resistant paints is described. Films produced from the following formulation: Butyl titanate 100 parts, ethyl alcohol 30 parts, ground mica 30 parts, TiO_2 30 parts, and water 5 parts, all by weight, were resistant to water and concentrated NaOH, and only softened by concentrated HCl. A quartz rod coated with this mixture was maintained at 1000° C. for two weeks without the coating showing any sign of deterioration. Steel panels coated with a mixture of aluminium powder 30 parts, butyl titanate 50 parts, light mineral oil 10 parts, and butyl alcohol 10 parts, were allowed to dry for 30 min. and then subjected to the following treatment: 600° C. for 30 min., cooled and a second coat applied; 600° C. for 6 hr. and allowed to cool; 600° C. for 6 hr. and water-quenched; slow heating to 600° C. maintained for 2 hr. and quenched; subjected to high humidity at 42–48° C. for 16 hr.; and 600° C. for 6 hr. and water-quenched. The only result was that the second coating peeled off after the first quench; after that no further change occurred. In order to determine whether the aluminium–butyl titanate formulation could give protection against hot flue gases, the interior of a steel stack at Yallourn Power Station was painted with it. After 32 weeks there was no sign of deterioration, whereas orthodox heat-resisting paints had burned away completely. Unprotected sheet lost 0·15–0·20 oz./sq. ft. in ten days under the same conditions. It is understood that an Australian firm is proposing to produce these paints.—J. P.

New Mica Base Paint System Withstands Severe Atmospheric Conditions. J. G. Ford and A. J. Kuti. (Materials and Methods, 1950, vol. 32, Nov., pp. 58–61). This three-coat ' Coastal Finish ' was developed by the Westinghouse Electric Corp. for use on outdoor transformers. The primer coat is composed of an unnamed vehicle giving good adhesion and

flexibility, the pigments being zinc chromate and iron oxide. The second coat consists of overlapping mica flakes in a vehicle of modified phenolic and alkyd resins. The results of salt spray, acid, and alkali immersion, and coastal atmospheric exposure tests, show that the resistance of the system is definitely superior to that of a standard three-coat finish. P. M. C.

Effects of Acid Treatment on Acid and Abrasion Resistance of Porcelain Enamels. W. N. Harrison, J. C. Richmond, and J. R. Crandall. (Journal of the American Ceramic Society, 1950, vol. 33, Oct., pp. 314–320). Results are reported of investigations of the effects of pretreatment with weak organic acids on acid and abrasion resistance of 14 enamels opacified with titania or antimony oxide. Treatment at room temperature, particularly with acetic acid, effectively inhibited subsequent attack by 10% citric acid, but markedly reduced abrasion resistance of some enamels, particularly those opacified with titania. The effects are ascribed to preferential solution of alkalis leaving a silica-rich surface layer more resistant to further solution but less resistant to abrasion than the untreated enamel.—E. C.

A New Method of Protection Against Atmospheric Corrosion. (Tecnica e Industria, 1950, vol. 28, July, pp. 735–736). [In Spanish]. A liquid zinc-base paint known as Zincilate is described. It is claimed that a single coating will resist corrosion for 20 years. Zincilate adheres without a preparatory coating or previous chemical treatment of the surface. The 'electrolytic defence action' of the zinc in the coating is held in reserve against corrosion until the coating surface is broken. Zincilate is applied by a pistol or by dipping. Heating for 1 hr. at 150° C. after painting gives maximum life.—R. S.

Mica-Base Paint System Doubles Transformer Tank Life. J. G. Ford and A. J. Kuti. (Steel, 1950, vol. 127, Oct. 30, pp. 56–58). The life of Westinghouse distribution transformers has been more than doubled by a mica-base three-coat system designed to withstand oxygen, acids, salts, and alkalis in sea-coast and industrial atmospheres. The first coat contains pigments primarily of zinc chromate and iron oxide, the second coat consists of a resin vehicle containing selected mica flakes which overlap each other forming a shingle roof effect and the final coat contains resins and pigments to withstand weathering and to provide good appearance.—A. M. F.

The Prevention of Rust by Redlead/Graphite/Iron-Oxide Mixtures. K. Basting. (Metalloberfläche, 1950, vol. 4, Apr., pp. A54–A61). The use of red lead–graphite–iron oxide mixtures for rust prevention in place of pure red lead was investigated by accelerated atmospheric corrosion tests. Satisfactory results were obtained with as little as 10% red lead, provided that correspondingly greater quantities of iron oxide and graphite were added, and especially when high ratios of graphite to iron oxide were used. Preliminary treatment with 10% phosphoric acid gave better results than de-rusting by hand, as did pickling in HCl provided that care was taken to remove all traces of acid before application of the protective coating. Linseed oil varnish in every case gave better results when used as binder than 'Eistanfirnis,' as the latter contains a considerable amount of spirits which evaporate leaving a thinner film (60–65 μ as against 70–80 μ). O. H. G.

Powdered Steel as a Metallic Pigment, and as the Starting Material for the Manufacture of Iron Oxide Base Pigments. (Peintures, Pigments, Vernis, 1950, vol. 26, Nov., p. 457). A brief review is made of methods used in manufacturing steel powder, from both carbon and alloy steels. Reference is made to patents for the use of such powder in manufacturing iron oxide pigments, and also for the use of stainless steel powder for admixture with cement to give concrete with great surface hardness.—J. J.

POWDER METALLURGY

Powder Metallurgy. P. Schwarzkopf. (Mechanical Engineering, 1950, vol. 72, July, pp. 543–548). An outline is given of the course of development from the manufacture of ductile tungsten and molybdenum to the production of composite contact materials, cemented carbides, porous parts, and high-strength structural materials. The author believes that powder metallurgy will help to solve the urgent problem of the development of materials exhibiting satisfactory strength and corrosion resistance at very high temperatures.

Problems in Powder Metallurgy. H. W. Greenwood. (Metallurgia, 1950, vol. 42, Sept., pp. 176–178). Despite the progress made in powder metallurgical technique, many problems have yet to be solved and they cover a wide field. Probably the most important of them is the need for greater strength, as measured by yield point and tensile strength, and greater resistance to high temperatures. Promising solutions to these problems may result from investigations with combinations of metals with non-metallic refractories, which are briefly discussed.—J. J.

Rolling Strip from Iron Powder. G. Naeser and F. Zirm. (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 995–1003). Strip has been rolled continuously by feeding soft iron powder (0·03% C, 0·19% Mn, 0·028% P, 0·017% S, 0·30% O_2) from a hopper into the nip of a pair of rolls with axes parallel in a horizontal plane. The nature of the strip issuing from the rolls depends on the shape of the grains, the screen analysis, the width of the roll gap, and the diameter and speed of the rolls. The density of the pressed strip increases linearly with decreasing roll gap up to a critical value and then increases more rapidly. Increased rolling speed, up to a certain maximum which depends on diameter and roll gap, produces thicker strip with higher density. The roll pressure was determined from the density of the rolled strip by comparison with powder pressed in moulds. Pressures up to 6 tons/sq. cm. could easily be attained with the small experimental rolling mill. The thickness of the strips produced was between 0·35 and 0·75 mm. (0·25–0·35 mm. after further rolling). The preparation of thicker strip would require greater roll diameters. The tensile strength of the pressed strip decreases with increasing roll gap and thus with decreasing density. The influence of grain size and screen analysis on strip thickness is small; the thinnest strip was obtained with fine powder and the thickest with the ordinary sieve analysis (all grains less than 0·3 mm.). For technical application, only continuous sintering furnaces are suitable and very short times are required, *e.g.*, a fraction of a second at 1400° C. The sintering process consists of at least two overlapping stages. Further processing of the sintered strip may be carried out by repeated rolling with brief interpass anneals. Finished strip had a tensile strength of 30–32 kg./sq. mm. and an elongation of 25% and was suitable for deep drawing. The final anneal was carried out at 650° C. to avoid grain growth. Passing the sintered strip through carburizing gases results in the formation of steel strip. The carburizing speed of various gas mixtures was investigated over the range 1100–1200° C. Some experiments have shown the possibility of preparing strip from other metals and alloys and of producing laminated (bimetallic) strip.—J. P.

Rolling of Iron Powder: Recent German Experiments. R. A. Hetzig. (Iron and Coal Trades Review, 1950, vol. 161, Dec. 29, p. 1034). The author reviews the work of G. Naeser and F. Zirm (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 995–1004) on the rolling of atomized iron powder in a small experimental mill, and discusses the significance of their results.—G. F.

The Mechanism of Sintering. J. P. Roberts. (Metallurgia, 1950, vol. 42, Aug., pp. 123–130). A review is made of the present knowledge of the mechanism of sintering. The process is divided into two phases, the first stage being when the pores in the material are interconnected, the second when these pores are isolated. Evidence, both theoretical and practical, is examined of the relative importance of the following mechanisms: Evaporation–condensation, surface diffusion, volume diffusion, viscous flow, and plastic flow. The conclusions provisionally reached are that volume diffusion plays a predominating part in the first stage, and viscous and/or plastic flow in the second. There are 36 references.—J. J.

Preparation of Carbides—Part I. G. F. Hüttig, V. Fattinger, and K. Kohla. (Powder Metallurgy Bulletin, 1950, vol. 5, May, pp. 30–37). After an introduction by Hüttig, Fattinger discusses the effect of the surrounding gas atmosphere on the preparation of tungsten carbide and molybdenum carbide from initially solid materials. The atmospheres used in the experiments were: (1) Pure hydrogen plus 0·5% propane; and (2) 6 to 1·3 by volume mixtures of hydrogen with (*a*) HCl, (*b*) HBr, and (*c*) HI.—R. A. R.

The Mechanisms Involved in the Sintering of Hard Metal Alloys. W. Dawhil and K. Schröter. (Zeitschrift für

Metallkunde, 1950, vol. 41, Aug., pp. 231–233). Experiments were carried out showing that mixed powders of cobalt and tungsten carbide begin to sinter and to form a smooth surface at 900° C. At 1150° C. the cobalt grains have taken up to 10% of tungsten carbide in solid solution, and contraction, due to sliding of the grains, takes place. Above 1300° C. a liquid phase appears, and sintering is rapid; this is the temperature generally used, but it is emphasized that sintering can take place without formation of the eutectic phase.—N. MCE.

The Influence of the Plasticity of the Particles in the Sintering of Metal Powders. F. Skaupy. (Zeitschrift fur Metallkunde, 1950, vol. 41, Sept., pp. 301–303). It is pointed out that the area of contact of the particles must be increased by plastic yield before intermolecular or intercrystalline forces can come into play. The effects of temperature and hardness on the compressed powder can be studied through electrical conductivity or mechanical strength. When the plastic properties of the material are known, it is possible to find the maximum permissible grain size, or, with mixed grain sizes, the best temperature for the sintering process.—N. MCE.

Thermochemical Coated Metal Powders. J. E. Drapeau, jun. (Proceedings of the Sixth Annual Meeting of the Metal Powder Association, 1950, pp. 28–35). An account is given of successful attempts to coat cast-iron particles, which normally cannot be briquetted, with copper, nickel, and lead so that the product can be used for making powdered metal shapes. The coating was done by means of a modified Thermite reaction using cast-iron particles, and either copper oxide, nickel oxide, or lead oxide powder or mixtures of these, less than 10 microns in size. During the reaction, the cast-iron particles become coated with myriads of firmly adhering particles of copper, nickel, and lead. The coated cast-iron powder was then mixed with fluxes and other addition agents, pressed in a mould at 30 or 40 tons/sq. in. and sintered in hydrogen, mostly for 30 min. at 2050° F. Various atmospheres, CO_2, CO, H_2, N_2, etc., were tried for the coating process, and the ratios of metal to coating oxide used were 90 : 10, 80 : 20, 70 : 30 for Cu_2O, 74 : 13 : 13 for a mixture of Cu_2O and NiO, and 85 : 15 for NiO. The modulus of rupture, and green and sinter density are given for each product.—P. C. P.

The Use of Metal Powder Parts as Friction Material. L. P. Kane. (Proceedings of the Sixth Annual Meeting of the Metal Powder Association, 1950, pp. 59–74). The plant and practice used at the S. K. Wellman Co., Cleveland, Ohio, for the production of metal powder parts such as clutch and brake discs is described. A typical composition for the metal powder is C 6%, SiO_2 4·4%, Sn 5·4%, Pb 8·7%, Fe 7·4%, Cu 68·1%. The sintered compact is too weak mechanically, and has to be supported by a sheet-metal bore brazed to it during sintering. The core is prepared by normal methods such as blanking, shearing, nibbling, and piercing, and is protected by a thin electroplated copper or nickel film from oxidation during brazing. The compacts and cores are stacked, weighted down to maintain good contact, and furnace-brazed in a reducing atmosphere at 1250° F. to 2000° F. The finishing operations such as grinding, grooving, and grit-blasting are also described, and their advantages discussed.—P. C. P.

Application of Iron Powder in Radio and Television Circuits. F. W. Edwards. (Proceedings of the Sixth Annual Meeting of the Metal Powder Association, 1950, pp. 42–48). This is a general article in which the various powders, such as hydrogen-reduced iron powder, magnetite, carbonyl powder, and 'Ferrite' used for the production of cores, are briefly described. Some of the radio and television components in which these cores are used are illustrated.—P. C. P.

A New Type of Stainless Powder. G. Stern. (Proceedings of the Sixth Annual Meeting of the Metal Powder Association, 1950, pp. 49–56). Experiments carried out on a new type of stainless powder produced in two grades, 140 (with 14% Cr, 0·02% C), and 188 (with 17–18% Cr, 8–9% Ni, 0·04% C) are described. The method of manufacturing this powder is not stated. The tensile and density properties of these powders as pressed and sintered, and as pressed, sintered, re-pressed, and resintered are given, all sintering being carried out at 1300° C. for 1 hr. Grade 140 develops higher densities and superior physical properties than grade 188 for equivalent sintering treatments. After pressing at 35 tons/sq. in., followed by sintering for 1 hr. at 1300° C., an ultimate tensile strength of 30,250 lb./sq. in. and an elongation of 7·8% are obtained for grade 140. The physical properties of the powders are improved by the re-pressing and resintering treatments. It is claimed that both powders have excellent mouldability, their green strengths are far superior to any commercial alloy powders of similar chemical composition, and that the sintered strengths are adequate. The work was extended by determining the effect of silver and copper infiltration on grade 140 powder.—P. C. P.

Infiltrated or Impregnated Alloys. H. W. Greenwood. (Engineer, 1950, vol. 190, Oct. 20, pp. 384–385). The author discusses the recent developments in the technique of impregnation and infiltration. Impregnation covers processes such as the filling of pores of a sintered or unsintered metal compact with a metal or alloy of lower melting point. Infiltration is generally applied to the filling of pores of a compact with a metal or alloy of lower melting point by capillary action. It is suggested that the study and application of these techniques may become the most important development in powder metallurgy in our time.—M. D. J. B.

Application of Dilatometry to Powder Metallurgy. J. H. Andrew and G. S. Tendolkar. (Journal of Scientific and Industrial Research, 1950, vol. 9, Oct., pp. 244–247). A modified horizontal dilatometer has been designed and used to study volume changes of pressed copper powder specimens during heating.—J. P. S.

An Electrostatic Method for the Determination of Specific Surfaces of Powders. J. Svensson. (Jernkontorets Annaler, 1950, vol. 134, No. 10, pp. 534–537). [In Swedish]. According to a theory put forward by Gucker and O'Konski, the charge that particles receive by colliding with a metal surface should be proportional to the squares of the diameters, *i.e.*, proportional to the surfaces. The author has constructed an apparatus and worked out a method for measuring these charges and has tested different powdered materials. Comparison with values obtained by the permeability method shows that the particle charge, although chiefly determined by the surface, is also influenced by several other factors. A thorough investigation might lead to a wholly acceptable electrostatic method for determining specific surfaces.—B. S. E.

PROPERTIES AND TESTS

Considerations on the Relationship between Stress and Strain in Plastic Metals. J. H. Palm. (Metalen, 1950, vol. 5, Sept., pp. 9–14). [In English]. A formula relating the true stress and logarithmic strain in monotonic uniform uniaxial tension and compression is extended on the basis of energy considerations. A modification of the formula is given for metals which are fully anisotropic, and for partially anisotropic metals. A formula developed by Mazzoleni (Metallurgia Italiana, 1941, vol. 33, p. 390) is discussed and a fundamental weakness is explained.—R. S.

Reflection of Shock Waves in Resilience Test Pieces during Pulling. S. Travers. (Mémorial de l'Artillerie Française, 1949, vol. 23, No. 4, pp. 847–858). A theory is advanced to explain the results which can be obtained in testing specimens for resilience by exerting a sudden tractive effort on them. This theory is based on considerations of the velocity with which shock waves are transmitted, and being reflected inside the test piece, the interference between them.—J. J.

Steel Castings Test Blocks : A Review of Available Data. H. T. Protheroe. (Iron and Steel, 1950, vol. 23, Mar., pp. 79–84). The author reviews the literature pertaining to the design of test blocks for the provision of tensile-test blanks for cast steel, and from a critical analysis of test results concludes that separately cast blocks are better criteria of steel quality than test pieces cut from castings. Recommendations on the design of test blocks are included. The value of test pieces cut from castings depends largely on their position; those cut from thin sections of a casting give better mechanical test results than those from thicker sections, whilst pieces cut from the centre of heavy masses give only moderate mechanical test results.—G. F.

The Theoretical Background and Interpretation of the Schnadt Impact Test. J. H. Palm. (Metalen, 1950, vol. 4, May, pp. 177–184; June, pp. 213–217; July, pp. 231–236). [In English]. The author, using a survey by W. L. H. Schmid of a lecture by Schnadt to the Netherlands Institute of Welding on Feb. 25, 1949, summarizes the assumptions of the theory of plasticity on which Schnadt has apparently based his system. Schnadt's attempt to evaluate the sensitivity of steel to cold brittleness on the basis of impact values

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and his system of a special series of notched test bars is explained. The relation between the impact value and quantities such as notch-sharpness, width, size effect, strain rate, and temperature are surveyed in relation to a qualitative evaluation of steel quality. In view of the difficulty in precisely determining the local triaxiality of the stresses in actual structures, a qualitative relation cannot be given.

R. S.

The Physics of the Deformation of Metals. E. N. Da C. Andrade. (Endeavour, 1950, vol. 9, Oct., pp. 165–177). The author describes recent work in the systematic study of the properties of metals and explains why the study of solids or liquids is so much harder to carry out compared with the study of the gaseous state. Many different structures in metals are possible under identical conditions and the mechanical properties are largely determined by small irregularities in the crystal lattice. Investigations carried out with metals in a single crystal form have done much to reveal the essentials of the problems of deformation. Regarding polycrystalline metals, the phenomenon of creep, *i.e.*, the slow flow under high stress, has recently received much attention. From these studies, certain general laws have been established which open up further interesting speculations; these are now engaging the attention of both academic and industrial scientists. There are 16 references.—T. W. H.

The Significance of "Fry Lines" in Mild Steel. A. Fry. (Instituto del Hierro y del Acero, 1950, Supplement to vol. 3, July–Sept., pp. 5–13). [In Spanish]. During research on the harmful effects of phosphorus segregations in steel, the Heyn and the Rosenhain-Oberhoffer reagents were used. The author noticed that, with the Heyn reagent, there was deep corrosion of the phosphorus segregations, whilst, with the Oberhoffer attack, the iron zones were attacked but the phosphorous segregations were covered by a thin, compact, visible layer of metallic copper which protected the phosphorus areas from further chemical attack. By varying the concentration of hydrochloric acid in the Oberhoffer reagent, new corrosion patterns were observed. In the steam boiler plates under examination, these peculiar corrosion marks appeared directly after treatment. The author was, however, able to obtain the same 'attack lines' by subjecting the steel to mechanical stress, with and without subsequent tempering.

The difference between the 'Fry' lines and the well-known 'Luders lines' is that the latter are observed only on the surfaces of deformed materials during straining or flow, and appear in every mild steel. The former appear internally in sections subjected to tensile stresses, and are usually associated with a heat-treatment. The effects of varying degrees of deformation on these lines and the possibility of them being due to slip is discussed. Attention is drawn to the relationship between 'Fry' lines, ageing, and blue brittleness.—R. S.

The Flow and Fracture of a Brittle Material. L. F. Coffin, jun. (Journal of Applied Mechanics, 1950, vol. 17, Sept., pp. 233–248). A notch effective stress in grey cast iron can be calculated for a critically situated crack from a knowledge of the external stresses, a plastic stress-concentration factor of 3, and a residual tensile stress at the sharp edge of the crack, based upon either the 'maximum shear' theory or the 'distortion-energy' theory. This allows the formulation of generalized plastic stress–strain relationships and renders grey cast iron applicable to the many known solutions for plastic flow of ductile materials. A combined stress-testing programme is described wherein thin-walled cast-iron tubes are subjected to two-dimensional states of combined stress covering the complete two-dimensional field.—J. P. S.

Stress Analysis by the Brittle Varnish Method. B. Salmon. (Technique et Science Aéronautiques, 1949, No. 6, pp. 343–362). A description is given of a technique for examining the deformation under stress of variously shaped test pieces by covering the polished surface of such specimens with a closely adhering film of varnish which has low ductility and cracks when the metal underneath is distorted, giving visual indication of the stresses applied. Many examples and illustrations are given of the application of this technique.

J. J.

Electrical Resistance Strain Gauges and Measuring Instruments. R. Jamieson. (New Zealand Engineering, 1950, vol. 5, July 15, pp. 598–605). The purposes, advantages, construction, and applications of strain gauges are discussed. Tests on electrical resistance gauges showed that the gauge factor k (ratio of relative variation of the resistance to the relative variation of length could be guaranteed linear up to 1% strain. Measuring bridges for static and dynamic loads are also described and illustrated, and details of the construction of Philips ground pressure and water pressure pick-ups and dynamometers are given.—R. A. R.

Analysis of Experimental Data Regarding Certain Design Features of Pressure Vessels. G. J. Schoessow and E. A. Brooks. (Transactions of the American Society of Mechanical Engineers, 1950, vol. 72, July, pp. 567–577). The authors analyse data obtained by strain gauge experimental stress analysis on drum heads and nozzle openings in drum shells. This analysis, while referred particularly to power boilers, is also applicable to other types of pressure vessel. The data obtained are reduced to dimensionless form so that they may be applied to drums of other sizes and thickness but geometrically similar. The relationship between operating-stress level and the life of the vessel in service is discussed with particular reference to a drum that has given over 40 years of satisfactory service. The effect of prestress created in the vessel by applying the 1½-times working-pressure hydrostatic test, is discussed.—D. H.

Thermal Cracks in Turbine and Generator Rotor Forgings. A. W. Rankin, C. J. Boyle, C. D. Moriarty, and B. R. Seguin. (Mechanical Engineering, 1950, vol. 72, July, pp. 559–566). The paper deals with the work done at the works of The General Electric Co., Schenectady, to ensure that no faulty turbine or generator rotors were put into service. The authors present: (1) A general review of the results of ultrasonic testing during a short period when it was difficult to ensure that the forgings were free from thermal cracks. The results from the first three rotors are discussed in detail; (2) a discussion on the practical details of ultrasonic testing of large rotor forgings with special emphasis on the need for careful interpretation of the results; (3) metallurgical investigations on particular rotors, with a tabulation of identifying characteristics of thermal cracks and non-metallic inclusions; and (4) a description of the spin tests which were made to determine the reduction in bursting speed of a rotor resulting from thermal cracks of a size and distribution found in the investigation.—D. H.

Investigation into the Premature Failure of Welt Needles. (Journal of the Birmingham Metallurgical Society, 1950, vol. 30, Sept., pp. 96–107). Premature breakages in English-made welt needles by comparison with American needles led to an investigation of both types. The results of comparisons of surface finish, composition, shape, hardness, resistance to hydrochloric acid, and microstructure are given. The failures were due to the cumulative effect of several factors such as surface finish, anti-corrosion treatment, and microstructure.

R. A. R.

Fatigue of Metals: Consideration of Orowan and Dehlinger Theories. P. Feltham. (Iron and Coal Trades Review, 1950, vol. 161, Nov. 3, pp. 599–604). The author first indicates the importance of knowledge of the mechanism of fatigue, and discusses past investigations. The resistance of a metal to deformation is considered, and the fatigue theories of Orowan and of Dehlinger are discussed in detail. Attention is also paid to criticism of Orowan's theory advanced by other investigators.—G. F.

Engineering Steels under Combined Cyclic and Static Stresses. H. J. Gough. (Journal of Applied Mechanics, 1950, vol. 17, June, pp. 113–125). In the testing machine cyclic loading moments are produced by the centrifugal forces of unbalanced weights attached to revolving discs driven by a synchronous motor. The test material was a nickel–chromium–molybdenum–vanadium steel. Tests were carried out on solid and hollow specimens containing one of three forms of discontinuity of section. The results are tabulated.

J. P. S.

The Influence of Shape of Cross-Section on the Flexural Fatigue Strength of Steel. T. J. Dolan, J. H. McClow, and W. J. Craig. (Transactions of the American Society of Mechanical Engineers, 1950, vol. 72, July, pp. 469–477). The flexural fatigue strength of a beam is influenced to an appreciable extent by the shape of cross-section of the member. In order to obtain further information on the magnitude of this shape effect, flexural fatigue tests were made employing four different shapes of cross-section for each of two different steels. The results are compared and analysed to clarify the shape factors that may be of importance

in affecting fatigue behaviour. It is concluded that variations in residual stress or alterations of properties due to different methods of machining the shapes play only a minor part in affecting the relative endurance limits. The susceptibility to localized inelastic action as governed by the shape of the cross-section and by the presence of outwardly projecting corners, is tentatively believed to be the primary element leading to the differences noted in flexural fatigue strengths. D. H.

Experimental Technique in Pressure-Vessel Testing. L. F. Kooistra and R. U. Blaser. (Transactions of the American Society of Mechanical Engineers, 1950, vol. 72, July, pp. 579–589). The latest designs of pressure vessels for high-pressure boiler service have been investigated by means of experimental stress analysis and hydraulic fatigue tests. Methods have been developed to measure strain on the inside as well as on the outside of pressure vessels under internal pressure. Pulsating hydraulic fatigue tests were conducted on full-scale high-pressure drums. Scale-model vessels of about one-tenth actual size were similarly tested in a saturated steam and water atmosphere of 2000 lb./sq. in. The testing technique and the special apparatus are described.—D. H.

Fatigue Tests on Flanged Assemblies. A. R. C. Markl and H. H. George. (Transactions of the American Society of Mechanical Engineers, 1950, vol. 72, Jan., pp. 77–87). The investigation reported contributes towards an understanding of the effects of the variable bending moments associated with mechanical vibrations or temperature fluctuations of the flowing medium or surrounding atmosphere. Stress-intensification factors are reported which have been obtained from fatigue tests on full-scale assemblies of 4-in. flanges of the 300-lb. A.S.A. pressure class and hence are directly applicable to calculations of piping flexibility. The tests established that even under unusually severe bending stresses, flange assemblies do not fail in the flange proper or by fracture of the bolts, or by leakage across the joint face. Structural failure occurs almost invariably in the pipe adjacent to the flange and in rare instances across an unusually weak attachment weld. Leakage in advance of failure is observed only in the case of threaded flanges. While it is the pipe that fails the type of flange is influential in determining the endurance limit of the assembly. A welding-neck flange provides an endurance strength equivalent to that of a butt-welded joint. A fillet weld provides less favourable conditions than does a lap-joint flange. In the case of threaded flanges, the reduced pipe-wall thickness and notch effect caused by the threading constitute weaknesses which become even more apparent under cyclic loading than under static conditions. D. H.

Contribution to the Study of Hardness and the Work-Hardening Capacity of Metals. J. Terraza Martorell. (Instituto del Hierro y del Acero, 1950, vol. 3, Apr.–June, pp. 132–149). [In Spanish]. The author considers methods of determining the capacity of work hardening of metals, especially the application of Meyer's law. From the Hertz laws of elastic penetration a modulus of plasticity is introduced equivalent to Young's modulus in the plastic sphere. The Meyer's constants are calculated from the variations of this modulus of plasticity with penetration. From these constants, it is possible to calculate the limit of plasticity of the material and to determine its 'elastic hardness.'—R. S.

Precipitation Processes in Steel. A. Fry. (Instituto del Hierro y del Acero, 1950, Supplement to vol. 3, July–Sept., pp. 59–71). [In Spanish]. The author discusses phenomena in those processes of precipitation which do not cause mechanical deformation. This type of precipitation is characterized by an increase in hardness. The network mechanism of the processes is explained by a series of diagrammatic models.—R. S.

The Quench Hardenability of Steels and Its Determination. H. Schottky. (Stahl und Eisen, 1950, vol. 70, Oct. 12, pp. 909–924). A review of the literature on hardenability tests indicates that these are concerned less with hardness than with depth of hardening as a function of grain size. The tendency to transform in the martensite range is characterized as quench hardenability. Since the kinetics of transformation depend on nucleation phenomena, the depth of martensitic hardening is determined by a competition between the tendency to transform and the rate at which cooling proceeds. A description of the Jominy end-quench test is given. The course of cooling over the length of the specimen corresponds to that of a plate quenched on one side; it can be calculated or measured with thermocouples. Since various steels show little difference in their cooling behaviour, each distance from the quenched end corresponds to a certain cooling rate. The Jominy end-quench test is particularly suitable for testing the hardenability of alloyed constructional steels with ideal critical diameters of 20–150 mm. It is less suitable for deeper hardening steels, whilst for poorly hardening unalloyed materials a special test piece is recommended. The Jominy test has shown itself to be an excellent means for assessing the influence of chemical composition and metallurgical and thermal treatment on hardenability. The criterion for the test curves for the course of hardening over the length of the specimen is the distance from the quenched end to the place where a certain hardness or proportion of martensite is not exceeded. The limit of 50% martensite has been widely adopted. It has been indicated that, for steels of the same nominal composition, samples taken from the same cast or from casts of the same heat show only small variations in hardenability, but that samples from different heats show marked differences.—J. P.

Contribution to the Problem of Testing the Quench Hardenability of Structural Steels. R. Pusch. (Stahl und Eisen, 1950, vol. 70, Nov. 9, pp. 1064–1069). The results are reported of an investigation aimed at standardizing hardenability testing of alloy steels. Samples were quenched by complete immersion and by end-spraying. For depth of hardness determination on immersion-quenched specimens a turned test piece at least 70 mm. in dia. was found preferable. It is recommended that the complete hardness-depth curve be used for assessing hardenability, although in certain circumstances, hardness determinations at the core, at the surface, and at a distance of 15 mm. from the surface may suffice. Similar considerations hold for the end-quench test, depth here being understood as the distance from the quenched face. The investigation showed that neither the McQuaid–Ehn grain-size estimation nor testing for overheating susceptibility was a suitable criterion for hardenability.—J. P.

Experiences in Testing the Hardenability of Steel by the End-Quench Test. E. Rossow and L. Schmidt. (Stahl und Eisen, 1950, vol. 70, Nov. 9, pp. 1069–1073). Of the different procedures for determining hardenability, the end-quench has proved to be the most suitable routine test for low and medium alloy steels because of its simplicity, rapidity, reliability, and small consumption of material. It is insensitive to changes in the nature and temperature of the quenching water but, depending on the type of steel, it is sensitive to quenching and tempering temperature. Tests on the hardened and on the annealed end-quench test pieces allow the tensile strength of the core to be predicted with a fair degree of accuracy. The end-quench test gives important information about the effect of steel composition on through-hardening and heat-treatability and is suitable for determining hardening and tempering temperatures, susceptibility to overheating and secondary precipitation effects, but it is not so suitable for assessing the quenching action of various hardening media. Experimental results have shown that the end-quench test can be correlated with results on immersion-quenched specimens.—J. P.

New Developments in Hardness Testing. P. Grodzinski. (Schweizer Archiv, 1950, vol. 16, Nov., pp. 335–340). Two new machines, for testing very hard materials, such as the carbides of tungsten, silicon, and boron, are described. The first uses a double-conical diamond indenting tool, the edge formed by the junction of the two conical surfaces making a boat-shaped indentation whose length gives a measure of hardness. When used on hard materials it has a longer life than a Vickers diamond pyramid, and if the edge breaks it can be turned to expose a new section of edge. Loads up to 2 kg. can be applied, but its main field of usefulness is as a microhardness tester as it will test local directional properties. The second machine is a microwear tester. The tool, a cast iron double-cone of diameter 25 to 50 mm. fed with diamond dust in olive oil, is rotated at 10,000 to 20,000 r.p.m. in contact with the test piece. A load of 20 to 500 g. (normally 75 g.) is applied and the time of contact is only 15 sec. A very small, highly polished mark is made, which is readily measured.—H. R. M.

High Temperature Hardness Testing. (Metallurgia, 1950, vol. 42, Sept., pp. 207–208). Recent Russian work on hardness testing at high temperatures has been directed towards

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obtaining information on the high-temperature properties of alloys more rapidly than is possible by the usual methods. A Brinell machine fitted with a metallo-ceramic indenter has been used for this purpose.—J. J.

The Mechanical Ageing of Iron—Non-Ageing Steel. A. Fry. (Instituto del Hierro y del Acero, 1950, Supplement to vol. 3, July–Sept., pp. 48–58). [In Spanish]. The author traces the development of the conceptions of ageing from the work of Strohmeyer in 1885–1917. Later tests showed that all rimming steels had a typical propensity to ageing and the presence of 'Fry lines.' In these heats, manganese was used for deoxidizing. It was supposed that certain oxides such as manganese and iron oxides, dissolved in the liquid steel, were precipitated during cooling and formed zones of ageing. To confirm this supposition, it was necessary to convert the precipitating MnO–FeO compounds to a non-precipitating form. This was done by adding aluminium to form Al_2O_3. In this manner, steels were obtained which were, without exception, insensitive to ageing and did not form any 'Fry lines.' Other effects of precipitation, including intergranular corrosion, are discussed and the conditions on which the process of precipitation is based, are stated.

Characteristics of non-ageing steels are described. The purity of the ferrite network is conducive to slip and consequently guarantees a maximum capacity for deformation under triaxial stresses. A simple way of differentiating between ageing and non-ageing steels is the use of the triaxial stress impact test.—R. S.

New Vanadium Steel for Deep Drawing Sheets. S. Epstein and J. W. Frame. (Iron Age, 1950, vol. 166, Oct. 12, pp. 158–163). Vanadium-treated steel (1 lb. vanadium/ton), rims perfectly and combines the advantage of not ageing of aluminium-killed steel with the good surface characteristics of rimmed steel. The authors discuss the formation of stretcher strains and compare the stress–strain curves of ageing and non-ageing steels at room temperature and 400° F. Vanadium-treated steels, to be as ductile as possible, should finish their hot rolling at as high a temperature as possible and be hot coiled; for best non-ageing properties the annealing temperature should be on the low side and the cooling rate should be slow.—A. M. F.

Wearing Test on Materials for Cylinder Liners in Marine Engines. V. G. Kjær. (Transactions of the Danish Academy of Technical Sciences, 1950, No. 6, pp. 5–51). [In English]. Details are given of wear-testing machines, and a formula has been derived relating wear on test to wear in actual practice. The worn-off iron particles and iron particles in the used lubricating oil are measures of cylinder wear. The author advocates the employment of wear-testing machines on all new alloy liners before use in practice.—B. G. B.

The Foundry and Electrical Technology. E. M. H. Lips. (Metalen, 1950, vol. 4, Apr., pp. 157–165). [In Dutch]. The electrical and magnetic properties of cast alloys are surveyed. Various castings having magnetic and electric properties are illustrated. It is suggested that the electrical industry is not yet making full use of foundry possibilities. R. S.

Magnetic Sheets. E. Diaz-Varela Ceano-Vivas. (Instituto del Hierro y del Acero, 1950, vol. 3, Apr.–June, pp. 115–131). [In Spanish]. The properties of magnetic sheet are defined. Rolling methods are surveyed, and attention is drawn to the difficulties of achieving uniform thickness. The causes of hysteresis and Foucault losses are discussed, with a view to determining the optimum structure to minimize electrical losses. Special importance is attached to annealing. Methods of testing electrical properties are described.—R. S.

Supersonic Examination of Boiler Plate and Welded Seams. (Engineering, 1951, vol. 171, Jan. 5, pp. 29–30). This article describes the supersonic method of testing boiler plates adopted by Babcock and Wilcox, Limited. A beam of 2¼ megacycles frequency is sent through the thickness of the plate, and the observation of a single strong echo from the back surface of the plate can be taken as proof of sound metal. The presence of piping results in a reflection of the supersonic waves which is noted on the oscilloscope at a position corresponding to the mid-thickness of the plate. The types of defect experienced in plates are considered. A brief description is also given of X-ray inspection equipment. With very few exceptions, the supersonic technique did not fail to indicate the presence of defects which were later proved to be sufficiently serious to be unacceptable to current specification requirements.—M. D. J. B.

Ultrasonic Developments. P. V. Danckwerts. (Power and Works Engineering, 1950, vol. 45, July, pp. 233–239). The author describes what is meant by 'ultrasonics' and shows how, for a transmitter of given size, it is possible to produce and concentrate more energy in a given volume of a medium than can be obtained with audible sounds. The two major methods of producing ultrasonics, the use of the piezoelectric and magnetostrictive effects, are explained and their relative limitations discussed. The uses to which they are put, such as submarine detection, echo sounding, and the testing of materials are detailed and possible future uses in many fields are suggested, particularly where the phenomenon of cavitation can be employed.—A. M. F.

Damping Capacity: Part 1—Introduction and Technique of Measurement; Part 2—Effect of Conditions of Measurement; Part 3—Effect of the Specimen; Part 4—Correlations and Conclusions. E. Linacre. (Iron and Steel, 1950, vol. 23, May, pp. 153–156; June, pp. 285–288; Aug., pp. 344–348). This survey of the literature is divided into four parts. In Part 1, the author discusses the definition and importance of damping capacity and methods of measurement. He shows that past work can be divided into two distinct groups: (1) Work mainly of engineering value, and (2) work by physicists at much smaller maximum amplitudes, which is chiefly of metallurgical value. The author then considers the results of past work, and in Part 2 discusses the effect of conditions of measurement, dealing with the amplitude, mode, and frequency of vibration and the temperature and duration of testing, whilst in Part 3 the condition of the specimen is considered, the effect of composition and grain size, heat-treatment, and cold work, imperfections in the specimen, and ferromagnetism, being discussed. In Part 4, attempts to correlate damping capacity with other physical properties are considered, its non-dependence on other physical properties in general confirming that it is in itself a real physical property. Past results are briefly summarized and tabulated for a variety of conditions of measurement and of the specimen. The survey shows that methods of measurement vary in accuracy, those at low vibration amplitudes being most sensitive, and the interpretation of the results is largely explained by the theories of Zener. A bibliography of 167 references is included.—G. F.

A Test for the Dimensional Stability of Gauges by an X-Ray Diffraction Method. C. Wainwright and L. W. Nickols. (National Physical Laboratory: Metallurgia, 1950, vol. 42, Dec., pp. 401–404). Unless hardened steel gauges have been given a low-temperature stabilizing treatment after hardening, a change of size may occur in the first year of ageing. A method is described in which the breadth of the lines in the X-ray diffraction pattern of the steel are measured with a Geiger-Müller counter spectrometer, and the breadth is correlated with the stability of the gauge. The method will not distinguish between the stable and unstable conditions if the gauge has been so severely machined as to cause a structural change in the surface layers.—J. B. B.

Electronic Controller for Use with High Temperature Creep Testing Equipment. F. Gartside. (Metallurgia, 1950, vol. 42, Sept., pp. 211–216). In the controller described, modifications to the original Prosser circuit include an alteration in the Wheatstone bridge network, provision of adequate compensation for variations due to changes in temperature of the resistance thermometer leads, and the incorporation of a visual bridge balance indicator. Performance characteristics are given.—J. J.

Rapid Oxidation of Metals and Alloys in the Presence of MoO_3. G. W. Rathenau and L. J. Meijering. (Metallurgia, 1950, vol. 42, Sept., pp. 167–172). An account is given of experiments in which copper and heat-resisting copper alloys, iron and heat-resisting iron alloys, nickel and nickel–chromium alloys, and silver and silver–aluminium were oxidized at elevated temperatures in the presence of MoO_3 and air. MoO_3 promotes oxidation by the formation of liquid oxide phases, in which the atoms of the basic metal can take part. Owing to the incorporation of molybdenum into the scale the oxidation resistance may be affected below the lowest eutectic.—J. J.

Special Phenomena during the Oxidation of Heat-Resisting Steels and Alloys. W. Tofaute and G. Bandel. (Instituto

del Hierro y del Acero, 1950, vol. 3, July–Sept., pp. 177–186). [In Spanish]. After reviewing methods of evaluating the resistance to scaling by determining the average loss of weight per unit of area and time, the characteristics of tubular testing furnaces are described.

The type of the protective oxide layer depends on the quantity of alloying elements in the steel, the temperature and duration of oxidation, and the gaseous atmosphere. With the chromium–aluminium steels, this layer contains 95% aluminium oxide; with the chromium or chromium–nickel steels, 90% of the protective layer is chromium oxide. Where, however, there is an excess of oxygen a predominantly iron oxide layer is obtained. Iron oxide is extremely permeable to oxygen at above 550° C. A comparison of the different types of scaling in relation to temperature and time is illustrated diagrammatically. The oxidation of silicon steels is described and reference is made to the frequent occurrence of a secondary oxidation due to the perforation of the oxide layer by segregations rich in iron oxide. The effect of intense local oxidation is illustrated graphically in the case of a 14% chromium steel with 2·5% aluminium where the loss-of-weight/time curve rises steeply above 1100° C. Internal inclusions on the protective layer, *e.g.*, the segregation of nitrides, impoverishes the surface layer in those elements required to form the necessary impermeable protective oxides. The influence of the elements boron, vanadium, molybdenum, and wolfram on the protective layer is explained.

Finally, some oxidation 'crystalline growths' of acicular and pyramidal form are illustrated.—R. S.

Factors Affecting Deformation and Rupture of Metals at Elevated Temperatures. F. B. Foley. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 845–850; Journal of Metals, 1950, June). The resistance of metals to deformation and fracture at elevated temperatures is discussed, atomic structure and atomic movement in particular being considered the chief factors determining mechanical properties. Phase changes, the nature of grain boundary material, and grain growth are discussed in some detail, and the relationship between rate of deformation, elongation, and time to fracture is considered.

G. F.

Properties of Metals at Elevated Temperatures. G. V. Smith. (Mechanical Engineering, 1950, vol. 72, Oct., pp. 799–804). This is a brief consideration of the properties of metals at elevated temperatures. The phenomenon of creep is discussed in detail together with its implications. The microstructural changes at high temperatures, scaling, and other corrosion effects, and the effect of temperature on certain physical properties such as Young's modulus, thermal conductivity, and expansion are briefly mentioned.—D. H.

Heat-Resisting Steels, Especially for Temperatures up to 600° C. in Steam. W. Tofaute. (Instituto del Hierro y del Acero, 1950, vol. 3, July–Sept., pp. 195–202). [In Spanish]. The principles of creep testing are outlined. The behaviour of ferritic and austenitic steels in relation to creep is discussed. The significance of precipitation hardening and the effect of structure on creep resistance are examined. The mechanical properties at room temperature and the DVM (German) creep values are given for five steels and the effect of various previous treatments is shown. Relationships between testing temperatures, the creep, and fatigue limits are indicated.

R. S.

Heat-Resisting Steels and Alloys. (Aciers Fins et Spéciaux Français, 1950, Nov., pp. 32–34). The qualities required are resistance to corrosion at high temperatures and structural and dimensional stability, *i.e.*, resistance to cracking and creep. Three classes of alloys have these properties: (1) Ferritic steels with a chromium base; (2) ferronickels rich in chromium; and (3) chrome ferronickels rich in nickel. The chromium content is always $\geqslant 12\%$ in heat-resisting alloys.

E. C. S.

Tubes and Piping for Superheated Steam. (Aciers Fins et Spéciaux Français, 1950, June, pp. 46–48). In French power stations, steam coils operating at 510° C. are made from E.M.8 steel containing 5% Cr, 0·5% Mo, 1·5% Si, and 0·6% Al. For temperatures $> 510°$ C. a steel which is even more resistant to creep such as E.M.10, containing 9% Cr and 1% Mo with no other additions, is required. A weldable steel known as Chromesco 3 or Thermos 3, which contains 2·25% Cr and 1% Mo, is used for large pipes and collectors with a maximum operating temperature of 537° C. A new Cr–Mo–V steel ('Valimphy') which has recently been developed by Aciéries d'Imphy and made into pipes by Société Vallourec, can be used at temperatures up to 560° C.—E. C. S.

Thermal-Shock and Other Comparison Tests of Austenitic and Ferritic Steels for Main Steam Piping. W. C. Stewart and W. G. Schreitz. (Transactions of the American Society of Mechanical Engineers, 1950, vol. 72, Oct., pp. 1043–1060). Thermal shock tests on 6-in. pipe and valve assemblies, representing both austenitic and ferritic steels in 80 and 160 schedules are described. The shock-testing procedure was devised to simulate conditions resulting from carry-over of boiler feed-water into main steam lines operating at 900 or 2000 lb./sq. in., and at 1050° F. Other test procedures described include cyclic deflection tests of full-size 'mock-ups' consisting of 160 schedule pipe and valves for simulating expansion bends. Results are reported for 'mock-ups' of both austenitic and ferritic materials which were tested at 2000 lb./sq. in. and 1050° F. Each assembly was subjected to 4000 or more deflections corresponding to expansion cycles that would obtain on heating up a piping system from room temperature to 1050° F. once every two days for approximately 20 years.—D. H.

Report of Graphitization Studies on High-Temperature Welded Piping of The Philadelphia Electric Company. J. B. Abele and A. E. White. (Transactions of the American Society of Mechanical Engineers, 1950, vol. 72, Jan., pp. 37–52). Summaries of the work which has been done by and for the Philadelphia Electrical Company in ascertaining the degree of graphitization in the piping system in the Chester, Schuylkill, and Richmond stations since 1946 are reported. The results of a full-size pipe tension test on a graphitized weld section are reported. Solution treatment for removal of graphitization is described with some physical test results.—D. H.

Gas Turbines: High Temperature and High-Strength Steels. G. G. Smith. (Iron and Steel, 1950, vol. 23, Mar., pp. 85–87, 98). Gas turbine development, particularly in the aircraft field, depends on close collaboration between designers and metallurgists. The need to use existing materials somewhat limits the designer at present, but efforts are being made to evolve better steels and alloys. In this article, the designer's requirements are considered in relation to the available high-temperature and high-strength steels and their properties.

G. F.

Application of Alloy Steels to High Temperature Steam Turbine Service. W. L. Fleisham. (Blast Furnace and Steel Plant, 1950, vol. 38, Oct., pp. 1183–1186; Dec., pp. 1447–1450, 1482). Creep strength and the influence of temperature and tempering time are discussed. The advantages of adding vanadium are reviewed.—J. P. S.

HCl-Resistant Alloys. B. Waeser. (Werkstoffe und Korrosion, 1950, vol. 1, Sept., pp. 345–349). The author reviews the literature and patents on the resistance of non-ferrous metals and alloys, cast irons, and steel to attack by hydrochloric acid. There are 36 references.—R. A. R.

Creep Characteristics of Austenitic Alloys in Relation to the Phase Diagram. A. M. Borzdyka. (Doklady Akademii Nauk, S.S.S.R., 1950, vol. 75, No. 1, pp. 37–38). The stresses corresponding to creep rates in the range 10^{-5} to 10^{-7} mm./mm./hr. at temperatures of 600 and 700° C. have been determined for a number of nickel–chromium–iron alloys. The stresses determining the position of the iso-creep curves of the ternary γ solid solutions do not differ by more than 30% from one another. Nickel-base austenite has a much lower creep resistance than nickel–chromium base austenite.—R. A. R.

Internal Friction of Metals at Very High Temperatures. T'ing-Sui Kê. (Journal of Applied Physics, 1950, vol. 21, May, pp. 414–419). In connection with the study of the internal friction peak (in friction–temperature curves) associated with the viscous behaviour of grain boundaries in metals, some other effects were observed at higher temperatures causing an additional internal friction in superposition with the high temperature branch of this internal friction peak. Observations made support the view that this internal friction is caused by the presence of dislocations in the interior of the specimen although the mechanism of giving rise to the internal friction is unknown. It is pointed out that a study of high temperature creep under very low stress may be conveniently carried out through the internal friction measurements described.—J. P. S.

The Effect of Compressive Stresses on the Linear Thermal Expansion of Magnesium and Steel. J. L. Rosenholtz and

D. T. Smith. (Journal of Applied Physics, 1950, vol. 21, May, pp. 396–401). A series of cylinders of annealed extracted pure magnesium and medium soft steel was subjected to a sequence of compressive stresses at room temperature and their respective coefficients of linear thermal expansion in the direction of stress application were determined for the range 20° C. to 100° C. The cylinders were then heat-treated to permit either recovery or recrystallization and the changes in length were measured. Characteristic curves are given for each metal in which the coefficient of linear thermal expansion and length changes are plotted as a function of the true compressive stress. It is shown that these properties may be used to determine the stress history of a test specimen for which characteristic curves are available. It is suggested that this stress analysis technique may find application in the study of rock deformation and in the investigation of metals both before and after failure.—J. P. S.

Thermal Segregation : A Mechanism for the Segregation of Hydrogen in Steel. G. Derge and E. E. Duncan. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 884–885 ; Journal of Metals, 1950, June). A mechanism for the segregation of hydrogen in steel, known as ' thermal segregation,' is proposed. The theory is dependent on the temperature gradients occurring in ingots during cooling, and on the variation with temperature of the solubility of hydrogen in steel, the change in solubility at the α–γ transformation having an important influence. In support of the theory, some preliminary experimental evidence is given showing hydrogen segregation in small ingots (about 4 × 4 in.) cooled at different rates.—G. F.

Gases in Steel—Hydrogen. A. Fry. (Instituto del Hierro y del Acero, 1950, Supplement to vol. 3, July–Sept., pp. 24–35). [In Spanish]. Hydrogen is one of those gases which are soluble in steel and do not form solid compounds. Factors affecting the solubility of hydrogen in steel are stated. Part of the hydrogen retained in steel can be extracted by heating *in vacuo* and a hydrogen extraction curve is shown. A test is described to confirm the two types of hydrogen diffusion (atomic and molecular). Krupp tests to prove the ' flake theory ' included blowing hydrogen into the bath, heating a steel free from flakes for a long period at 1150° C. in a hydrogen atmosphere, and annealing steel in hydrogen at high pressure at 550° C. All these methods produced flakes. When ingots containing flakes are forged, the flakes are closed and the hydrogen is diffused under pressure. The action of external and internal stresses during the formation of flakes is described. Some points in steelmaking associated with the idea of reducing the partial pressure of the hydrogen at the end of melting or at the time of pouring are discussed.—R. S.

Influence of Elements on the Properties of Steels and Alloys. J. Vazquez Lopez. (Anales de Mecanica y Electricidad, 1950, vol. 26, May–June, pp. 147–156 ; July–Aug., pp. 216–228 ; Sept.–Oct., pp. 276–284). [In Spanish]. The following elements are dealt with in detail : Nitrogen, oxygen, tantalum, tellurium, titanium, thorium, lead, selenium, silicon. The maximum nitrogen content possible in steel is 11% by weight but to obtain even 2 to 3% nitrogen, pressures of over 400 atm. would be required. Nitrogen forms two compounds with iron : Fe_2N with 11·15% nitrogen, and Fe_4N with 5·9% nitrogen. The iron–nitrogen diagram and the solubility of nitrogen in iron in relation to temperature, ageing, and nitriding are discussed. Elements with higher heats of formation are oxidized first although the relative density and temperature can modify this condition. Some typical steelmaking reactions are discussed in relation to the modern conceptions of oxidation. Oxygen generally lowers rapidly all mechanical properties of steel. The effects of similar quantities of phosphorus, sulphur, and oxygen on the mechanical properties are compared. The mechanism of deoxidation is discussed.

Lead improves the machinability but there are difficulties in making lead additions. Selenium improves machinability of certain steels, *e.g.*, low-carbon free-cutting steels where it can replace part of the sulphur. Silicon generally tends to precipitate the carbon as graphite. The iron–silicon alloys are discussed in detail as regards structure and properties. Titanium raises the temperature of the $\alpha \rightarrow \gamma$ transformation but lowers the $\gamma \rightarrow \delta$ transformation point. Like niobium, tantalum forms extraordinarily stable compounds with carbon ; it is used to avoid weld decay. It is added to aluminium–chromium steels for nitriding to increase the thickness of the nitrided layer. Metallic tantalum is totally immune from attack by organic or mineral acids and it confers a certain degree of such immunity on steel.

Tellurium is insoluble in iron at room temperature. It occurs as an inclusion with a very low melting point ; it improves machinability and maintains good forgeability without loss of ductility. In small quantities, tellurium tends to prevent graphitization in cast steel.

Titanium improves resistance to scaling at high temperature and confers structural stability. Effects of varying the titanium–carbon ratio on the elastic limit and creep value are discussed.

Thorium possesses a great affinity for oxygen. Additions of 0·2 to 1% of thorium improve slightly the mechanical properties and fluidity and produce a certain amount of desulphurization.—R. S.

Molybdenum. (Aciers Fins et Spéciaux Français, 1950, June, pp. 23–24). Molybdenum improves toughness, decreases susceptibility to temper brittleness, and increases resistance to softening on tempering. Molybdenum improves the corrosion resistance of chromium and chromium–nickel steels. It increases strength and creep resistance, retards softening, structural changes, and graphitization. The above properties make molybdenum useful as an alloying element in tool steels.—E. C. S.

Use of Vanadium in Special Steels. (Aciers Fins et Spéciaux Français, 1950, Nov., p. 11). Certain steels for machine parts contain 0·1–0·2% V and those for cutting tools contain 0·6–1·0% V. High-speed steels may contain as much as 5% V with 12–15% W and 4–5% Co. The carbon content of these steels increases with the vanadium content. A steel containing 5% V also contains about 1·4–1·5% C. These high-speed steels contain austenite which is particularly difficult to transform into martensite but, after many successive treatments, a steel whose hardness is of the order of 67 Rockwell may be obtained.—E. C. S.

Modern Cast Iron. M. M. Hallett. (Journal of the Birmingham Metallurgical Society, 1950, vol. 30, June, pp. 44–62). The characteristics of the following types of modern cast irons are considered : Those resisting (*a*) corrosion, (*b*) heat, (*c*) wear, and those with high-tensile strength. Curves show the corrosion rate of high-silicon irons in H_2SO_4, HNO_3, and HCl at boiling point over wide ranges of concentration. The resistance to scaling in air at 900° C. of several special irons is given. Nicrosilal should not be used between 500° and 650° C. The achievement of high wear resistance by nitriding, by heat-treatment to produce tempered martensite, and by chilling is discussed. The production of high-strength nodular graphite cast iron is briefly dealt with.—R. A. R.

Development, Significance and Uses of Specifications for Cast Iron. H. Bornstein. (American Society for Testing Materials : Foundry, 1950, vol. 78, Apr., pp. 78, 222, 224–227). The various revisions of standard specifications for cast irons, associated with the American Society for Testing Materials, are reviewed with the object of demonstrating the progress in the quality and properties of grey-iron castings. The period covered is about 30 years, beginning with the A.S.T.M. Standards for 1916.—E. J. D. S.

The Foundry and Engine Production. H. van Suchtelen and A. W. J. v. d. Bergh. (Metalen, 1950, vol. 5, Sept. pp. 1–8). [In Dutch]. The demand for better properties in castings, greater strength, wear resistance, weight saving, and mechanization of foundry technique is pointed out. The number of specifications for various classes of castings at the Kromhout Motor Works is listed. The properties of the following types of casting are discussed : Frames, cylinder blocks, liners, pistons, crank-cases, and bearings.—R. S.

Notch Sensitivity of Various Cast Materials. T. E. Eagan. (American Foundryman, 1950, vol. 18, Nov., pp. 22–24). Reverse bend tests were made on notched specimens machined from large sections of forged steel, cast steel, alloyed grey iron, acicular iron, and ductile cast iron. An R. R. Moore fatigue machine was used and the radius of the notch was 0·050 in. The effects of the notch were shown in the reduction of the endurance limit and the stress concentration factor K. Cast steel, acicular iron, and ductile iron had a tensile strength in the range 71,000 to 74,000 lb./sq. in., an unnotched endurance limit between 24,000 and 26,000 lb./sq. in., and a notched

endurance limit between 17,000 and 19,000 lb./sq. in. K for acicular iron was 1·53, cast steel 1·26, and ductile cast iron or nodular iron 1·3. For forged steel K was 1·96.—E. J. D. S.

Automotive Cast Irons. R. G. McElwee. (American Society for Testing Materials: Foundry, 1950, vol. 78, Sept., pp. 90–91, 214). The general requirements of automobile iron castings are discussed in relation to standard specifications. E. J. D. S.

Nodular Graphite Cast Iron. C. K. Donoho. (Product Engineering, 1950, vol. 21, Apr., pp. 140–144). The physical properties of nodular graphite cast iron are compared with those of ordinary flake graphite cast iron and it is shown that the former has higher ductility and tensile properties. This type of iron can fill the gap between cast steels and grey irons and may even replace cast steel where better castability and machinability are the deciding factors.—A. M. F.

Characteristics and Applications of Capped and Rimmed Steels. H. H. Smith. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 293–301). The production, structure, properties, and most important applications of capped and fully rimmed steels are briefly described and compared.—G. F.

Carbon and Low Alloy Steels. I. M. Mackenzie. (Metallurgia, 1950, vol. 42, Nov., pp. 282–284). During the past 21 years developments in the field of carbon and low-alloy steels have been greatly influenced by the impact of such problems as weldability and brittle fracture. On the production side, oil firing, combined with greater instrumentation and improved refractories, has led to greater output.—J. B. B.

Properties of Continuously Cast Special Alloy Steels. H. Krainer and B. Tarmann. (Stahl und Eisen, 1950, vol. 70, Nov. 23, pp. 1098–1106). A large number of casts of 19 different alloy steels were made with a continuous casting machine, having a mould 130 mm. in dia. The structures of these casts were compared with those of normal ingots prepared from the same melts, in the as-cast and in the hot-rolled states. The tensile strengths were determined. The results from the continuously cast bars were completely satisfactory. The degree of deformation in hot working necessary to break up the as-cast structure was less than that for the ingots; a four- to six-fold reduction proved satisfactory. No difference was noticed in the hardening properties of tool steels prepared by this method. The carbide distribution in ledeburitic tool steels was carefully investigated. The ledeburite network was finer with continuous than with ingot casting, so that the material required less deformation. Chemically resistant and chromium magnet steel could be satisfactorily cast continuously.—J. P.

Special Engineering Steels. (Tecnica Metalurgica, 1950, vol. 6, Mar., pp. 72–74). [In Spanish]. Fifty-five steels are listed by the Spanish Iron and Steel Institute. They are divided into eight groups: (1) Carbon steels; (2) high-tensile alloy steels; (3) case-hardening steels; (4) nitriding steels; (5) spring steels; (6) stainless steels; (7) heat-resisting steels; and (8) special application steels. Within each group, the steels are sub-divided according to contents of alloying elements. A full explanation is given of the system of numbering. Details of analysis range, hardenability, recommended heat-treatment, mechanical properties, and applications are given.—R. S.

Twenty-One Years of Progress in Special Steels. D. A. Oliver and J. S. Bristow. (Metallurgia, 1950, vol. 42, Nov., pp. 279–282). Developments in the last 21 years in the field of special steels are reviewed under the following headings: Engineering constructional steels; free-cutting steels; tool and die steels; and heat-resistant steels.—J. B. B.

Scientific Research in the Development of Alloy Structural Steels. L. B. Pfeil and L. W. Johnson. (Mémoires de la Société Royale Belge des Ingenieurs et des Industriels, 1949, Series B, Sept., pp. 171–194). A description is given of the development of alloy structural steels in recent years, and of the development of scientific methods of predicting their properties. Particular attention is given to the prediction of the hardenability of various types of steels and of **S**-curves, so that the requisite mechanical properties can be reliably obtained by heat-treatment. Detailed results of such experiments are given.—J. J.

New Corrosion-Resistant Materials Abroad. E. Franke. (Werkstoff und Korrosion, 1950, vol. 1, May, pp. 171–178; Aug., pp. 305–308; Sept., pp. 349–357). A review is presented of the corrosion-resistant alloys developed in Britain and the U.S.A. since 1945.—O. H. G.

The Development of High-Speed Steels. R. Scherer and W. Connert. (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 984–994). Development work on high-speed steels since 1938 is reviewed. An investigation was carried out using rough-turning as a measure to determine the optimum additions of alloying elements. Results on the influence of tungsten, molybdenum, vanadium, cobalt, titanium, chromium, carbon, and aluminium on cutting efficiency are reported. Attempts to develop a high-chromium steel were unsatisfactory and steels with additions of aluminium gave variable results. Steels utilizing the action of special nitrides, particularly aluminium nitrides, are of interest. A steel with 2·5–3% Mo, 3% V, 2·5–3% W, proved to be satisfactory for planing and milling cutters and for twist drills, being as good as steel with 1–1·5% V, 18% W, but its lack of toughness prevented its use for fine drills. A steel with 1·6% V, 9% W is, in general, as good as one containing 1% V, 18% W for drilling and milling. Cobalt-containing steels are preferably reserved for heavy turning, where hardness at red heat is required; 3–5% Co is usually adequate, higher contents being necessary only in special cases. Steels with high vanadium content are recommended for tools subject to very heavy wear; grinding difficulties must be borne in mind.—J. P.

Cold Forming Tools: Choice of Composition and Heat Treatment. (Iron and Steel, 1950, vol. 23, Apr., pp. 141–144). The fundamental properties required in tools for cold work are wear resistance, toughness, and safe-hardening, which are determined by the steel composition and heat-treatment. Twelve compositions of tool steels are listed, in each case the correct heat-treatment and the properties and uses being indicated; the steels include carbon tool steels and alloy steels for case-hardening, non-distorting tools, high toughness tools, and high wear-resistance tools. In addition the importance of tool design is discussed, and general considerations of the heat-treatment, finishing, and testing are given. G. F.

How to Select the 'Right' Cast Heat-Resistant Alloy. N. A. Mathews. (Steel, 1950, vol. 127, Nov. 6, pp. 90–94, 104–106). The problem of determining and utilizing the most economical alloy for a specific application is discussed. Extensive data on the performance of a number of chromium–iron, chromium–nickel–iron and nickel–chromium alloys designated by the Alloy Casting Institute are given. Their performance under conditions of hot ductility and resistance to corrosion, carburization, and thermal fatigue are compared. A. M. F.

The Present Status of Cast Iron. A. Wittmoser. (Stahl und Eisen, 1950, vol. 70, Sept. 14, pp. 813–828). Better mechanical properties of grey cast iron may be achieved by improving the strength of the metallic matrix or reducing the content of free carbon. The use of alloy additions to improve heat and corrosion resistance, and the developments leading to the production of acicular and nodular cast iron are described. The characteristics of these materials are compared with those of normal cast irons and steels. Nodular cast iron can be hot-worked and this has opened up the possibility of using a material which combines the advantages of steel with the superior properties of cast iron (low friction, good corrosion resistance, and reduced notch sensitivity). Improvements have been made to render malleable iron more resistant to abrasion; the addition of boron to increase the number of nuclei and so improve the distribution of carbon is described. In this field, the use of nodular irons promises to be an important innovation. The employment of alloy additions (nickel, chromium, and molybdenum) to increase the surface hardness and toughness of the core of chill castings has led to important developments in mill roll production, while additions of tellurium can be used to control the depth of the chill. Nodular chill cast iron is being used in America and Sweden for railway wagons.—J. P.

Wire Testing and the Evaluation of Common Tests Applied to Steel Rope Wire. L. R. Steuer. (Wire and Wire Products, 1950, vol. 25, Nov., pp. 978–979, 1005). This is an elementary article on the tests applied to rope wire. Among these are included gauging for size, the tensile and the torsion test. The author points out with regard to the latter that although specifications pay attention to the number of twists before fracture, the appearance of the fracture is in fact of greater importance.—J. G. W.

XUM

Some Results of Belgian Research on Nodular Cast Iron. A. L. De Sy. (International Foundry Congress, 1949, Metalen, Congress Issue, Part II, pp. 118–132). [In French]. The nature of spherulitic graphite is described. Production with magnesium is discussed and the requisite properties of an element suitable for promoting spherulitic crystallization of graphite are named. A detailed description of the work carried out at Ghent on 50 different alloys is given. An important phenomenon is the occurrence of 'vermicular' graphite ('quasi-flake graphite') alongside the spheroidal. There is a sudden increase in strength when the lamellar graphite changes to vermicular, and a second increase in strength on transformation to the spheroidal type. De Sy found that vermicular graphite caused a definite drop in elongation. The vermicular variety tends to form more readily with the cerium and lithium treatment than when magnesium is used.—R. S.

Heat Resisting Steels. J. F. Sewell. (Murex Review, 1950, vol. 1, No. 7, pp. 144–160). After defining a heat-resisting steel, the author details the properties under the headings: (*a*) Creep resistance, (*b*) scale and hot corrosion resistance, and (*c*) structural stability. From the metallurgical aspect the steels may be divided into three broad groups: Heat-treatable, ferritic, and austenitic steels. Details are given of the composition and properties of many commercial steels which fall into these groups. The author concludes with a summary of the more important points upon which information is necessary before the selection of the most satisfactory steel can be made.—B. G. B.

METALLOGRAPHY

Electrolytic Polishing and Its Application to Metallography. A. L. De Sy and H. Haemers. (Metalen, 1950, vol. 4, Mar., pp. 129–137). [In Dutch]. Electric polishing of soft metals and alloys saves time. The Beilby layer is extended to show the true structure and there is no mechanical disturbance of the metal. The mechanism of electrolytic polishing is illustrated by an example of the electric polishing of copper in ortho-phosphoric acid The resistance and the concentration theories are discussed. Details are given of methods for the electric polishing of iron, steel, and special steel, and aluminium and copper alloys Precautions necessary with perchloric acid baths are stated.—R. S.

An Electrolyte for Electrolytic Polishing and Etching. E. Knuth-Winterfeldt. (Jernkontorets Annaler, 1950, vol. 134, No. 10, pp. 538–539). [In Swedish]. An addition of 2-butoxy-ethanol to the electrolyte has proved beneficial, and the following bath composition is recommended: Perchloric acid (sp. gr. 1·2) 2 parts, ethyl alcohol 7 parts, and 2-butoxy-ethanol 1 part. A technical quality of the latter component called 'Butylcellosolv' was used.—B. S. E.

Identification of Structural Constituents of Stainless Steels. J. C. Jongebreur and C. Vollers. (Metalen, 1950, vol. 4, Aug., pp. 247–259). [In English]. After briefly describing the structural constituents of austenitic, martensitic, and ferritic stainless steels, the suitability of various reagents is discussed. A micromagnetic method is used to identify ferromagnetic structural constituents in austenite. Heat tinting proved suitable for identifying sigma phase, austenite, and carbides in stainless steels. A diagram is given illustrating the identification of structure components in stainless steels, indicating the possibilities of various etching reagents. R. S.

Electron Microscopic Studies of Metallic Structures by the Replica Method. M. Hillert and S. Modin. (Jernkontorets Annaler, 1950, vol. 134, No. 9, pp. 495–514). [In Swedish]. A general survey of the application of the electron microscope to the study of metallographic problems is given, and the authors' experiments with the polystyrene–aluminium replica and Formvar replica methods are described. The former often produced false structures whereas the latter method proved satisfactory The limit of resolution was found to be about 300 Å. Eutectic carbon steel undergoing different heat-treatments was investigated and the pearlitic and bainitic structures obtained are presented.—B. S. E

Apparatus for the Study by Electron Diffraction of the Effect of Temperature on Surface Films. J. W. Menter and J. V. Sanders. (Journal of Scientific Instruments, 1950, vol. 27, Dec., pp. 335–336) Two types of specimen holder are described for heating 'reflection' and 'transmission' specimens to be examined by electron defraction. In the range 15–200° C. the specimen temperature may be measured to within ± 5° C. A film holder is also described which enables 20 exposures to be made without breaking the vacuum of the diffraction camera.—H. D. W.

Solid Solubility of Cementite in Alpha Iron. C. A. Wert. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1242–1244; Journal of Metals, 1950, Oct.). By means of a technique involving measurement of the internal friction associated with the diffusion of carbon in α-iron, the author has determined the solid solubility of cementite in α-iron down to a temperature of 150° C., where the value is of the order of 4×10^{-5} wt.-%. Extrapolation gives a value for the solubility at room temperature of the order of 10^{-7} wt.-%, which is much lower than had previously been supposed. Measurements at higher temperatures agree closely with earlier determinations, which had been made at temperatures only as low as 400° C. The yield strength of ingot iron containing small amounts of cementite has also been determined as a function of carbon concentration, showing that the amount of carbon necessary to affect the yield strength is very small, about 0·0001 wt.-%.—G. F.

Relative Energies of Grain Boundaries in Silicon Iron. C. G. Dunn, F. W. Daniels, and M. J. Bolton. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1245–1248; Journal of Metals, 1950, Oct.). A description is given of an investigation made on 12 three-grain specimens of silicon–iron (3·31–3·38% Si) in order to determine the relative grain-boundary energies as a function of crystal orientation. The results for a (110) series in which each grain had a (110) plane in the plane of the specimen show a relatively rapid rise in grain-boundary energy with difference in orientation, whilst those for a (100) series in which each grain had a (100) plane in the plane of the specimen show a similar increase in grain-boundary energy with the curve reaching a maximum at a difference in orientation of about 30°. Micrographic data to show movement and configurations of boundaries are also given. G. F.

Crystallography of the Sigma Phase. P. Pietrokowsky and P. Duwez. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1283–1284; Journal of Metals, 1950, Oct.). By graphical examination of the differences in values of $\sin^2\theta$ for the adjacent lines of the powder diffraction pattern, the authors present details of an orthorhombic indexing of the patterns of the sigma phases of the six systems Cr–Co, Fe–Cr, Fe–Cr–Mo, Fe–V, Co–V, and Ni–V. In general, the similitude between the patterns is shown to be quite good, and some of the few differences are indicated.—G. F.

Orientation of Crystals Using a Geiger Counter X-ray Spectrometer. J. A. James. (Journal of Scientific Instruments, 1950, vol. 27, Dec., p. 326). A Geiger counter X-ray spectrometer is described for determining the orientation of large crystals (3 mm. in dia.) exposed in flat surfaces of metal, applied mainly to silicon–iron electrical sheet steel. The method enables thick samples to be studied without special surface preparation. Accuracy of 1° or 2° is obtained with certainty.—H. D. W.

X-Rays and Equilibrium Diagrams. J. J. Comhaire. (Technique et Humanisme, 1949–1950, vol. 47, No. 3, pp. 114–118). A brief description is given of the methods whereby X-ray diffraction patterns may be used to obtain the data necessary to establish phase diagrams. The methods described include the detection of phases by characteristic diffraction bands and the determination of the composition of a single-phase alloy by measurement of lattice parameters and back-reflection techniques.—J. J.

Influence of Boron upon the Kinetics of the Austenite Transformation in Steel. N. T. Gudtsov and T. N. Nazarova. (Izvestia Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk, 1950, No. 3, pp. 386–393). The transformations of austenite in a low-alloy steel (C 0·30%, Mn 1·20%, Cr 1·28%, Si 1·30%) with and without an addition of 0·0017% of boron were compared by magnetic methods, and the critical temperatures were determined with an optical dilatometer. The transformation of the boron-treated steel began considerably later than that of the boron-free steel. The addition of the boron alloy during melting caused a three-fold increase in the stability of the austenite. The critical temperatures of the boron-free and boron-treated steels were

Ac_1 770 and 770, Ac_3 880 and 900, Ar_3 770 and 765, and Ar_1 685 and 680° C. respectively. There was a tendency to reduced grain growth of the austenite when boron was present.—R. A. R.

Influence of Phase Changes below the A_1 Point on the Properties of Iron. W. Köster. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Sept.–Oct., pp. 305–314). Mechanical and magnetic ageing are produced by precipitation processes taking place as a result of the decreased solubility of carbon and nitrogen in iron at reduced temperatures. The processes have been investigated using the purest iron to which carbon and nitrogen have been added separately and then removed so as to ascertain their effects with certainty. The earlier results with technical iron have been confirmed. The influence of third elements has also been examined; their action varies according to the behaviour of the elements towards carbon and iron and the constitution of the resulting alloys. In contrast to ageing, mechanical and magnetic after-effects are to be attributed to carbon and nitrogen atoms in the undissolved state. In the undeformed α-iron lattice, carbon or nitrogen atoms are disposed uniformly at the middle of the cube edges or faces. If the lattice is extended in any direction, the cube edges in this direction become favoured sites for carbon atoms, which diffuse there from other sites. The result of this is the after-effect, which is thus to be considered as a diffusion process and which must obey the diffusion laws. Measurement confirms this. Under alternating stress, the mechanical (or magnetic) after-effect induces a frequency dependence of damping (or hysteresis loss); the damping has a maximum at medium frequencies. The value of this maximum is proportional to the number of interstitial carbon or nitrogen atoms, in conformity with the above concept of the cause of the after-effect. It is thus possible to follow by damping measurements as a function of time, the concentration changes occurring in an age-hardening steel. The end value of the precipitation isotherm gives the content of carbon or nitrogen atoms remaining dissolved. An accurate means for determining solubility is thus available. Utilization of the precipitation isotherms allows the length of the diffusion 'jumps' to be calculated. These are smaller in mechanical than in magnetic ageing (10^{-5} cm. as against 10^{-4} cm.). The product of a precipitation process can be checked by re-formation tests. These have shown that during ageing finely dispersed cementite is precipitated.—J. P.

Determination of the Constitution of Solid Metallic Systems by the Measurement of Electrical Resistance. H. Vosskühler. (Metall, 1950, vol. 4, June, pp. 231–235). The author recommends that when equilibrium diagrams are being set up with the aid of resistance measurements, both conductivity isothermals and temperature-resistivity curves be determined. The reason for employing both is that the former show clearly phase boundaries which run parallel to the temperature axis, whilst from the latter, phase boundaries parallel to the composition axis show up more clearly. The temperature-resistivity curves are also to be preferred for rising temperature measurements on previously annealed specimens because, especially at room temperature, saturation concentrations and temperatures can be determined more accurately; the instrumentation, too, is simpler. When there is a discontinuity in the resistivity–temperature curve and the temperature of the corresponding reaction is to be determined, then it is better to measure the resistivity at the equilibrium temperature. With regard to the specimen, small rods are to be preferred to wires. Low temperature equilibria are found more quickly by annealing of homogenized alloys at the appropriate temperatures than if the specimens are slowly cooled down to this temperature. The arguments are amply illustrated by temperature resistance graphs together with the appropriate equilibrium diagrams.—J. G. W.

CORROSION

Technical Standards Committee on Material Testing (FNM) of the German Standards Committee (DNA)—German Standards. Corrosion of Metals. Definitions. (DIN 50 900). (Metalloberfläche, 1950, vol. 4, Apr., pp. A62–A64). This is a proposed standard specification with definitions of 77 corrosion terms. O. H. G.

Corrosion and Protection Against It. A. Fry. (Instituto del Hierro y del Acero, 1950, Supplement to vol. 3, July–Sept., pp. 14–23). [In Spanish]. The author discusses some apparently contradictory phenomena in corrosion. The mechanism of scaling and the nature of protective layers are outlined. The nature of electrochemical corrosion is explained and the methods of evaluating the corrodibility of metals in electrolytes are described. Other aspects of corrosion which are noted are: Polarization; contact of unlike metals; formation of local cells. Some special types of corrosion, including a combination of 'Fry' lines and inter-crystalline corrosion, are illustrated. The influence of the annealing temperature subsequent to cold deformation on the inter-crystalline corrosion of mild steels of ageing and non-ageing types, is discussed.—R. S.

The Causes of Corrosion, Its Manifestations, Theories, and Methods for Its Prevention. W. Machu. (Werkstoff und Korrosion, 1950, vol. 1, June–July, pp. 265–277). This is a general review of the fundamentals of corrosion and methods of preventing it.—R. A. R.

Electrochemical and Chemical Oxygen Corrosion. F. Tödt. (Werkstoff und Korrosion, 1950, vol. 1, June–July, pp. 244–247). From the variation of the corrosion rate and rate of oxide removal with time for model galvanic electrodes it is concluded that metal surfaces which come into contact with an electrolyte after having been exposed to the air lose their surface layer of oxide by cathodic reduction after a relatively short time. This is true regardless of whether the oxide removal is caused by local cells, or by a second metal acting as anode, and means that except initially, or if there is periodic exposure to air, a corroding metal is only to a slight extent covered by oxide able to exert an electrochemical influence.—O. H. G.

The Causes and Effects of Galvanic Currents. L. W. Haase. (Werkstoff und Korrosion, 1950, vol. 1, Aug., pp. 297–299). When two different metals are each in contact with the same electrolyte, and with each other, the corrosion taking place does not usually correspond to the corrosion which would be produced by the galvanic currents to be expected in such a system. This assertion is illustrated by reference to the systems iron/copper/tap water; copper/aluminium/beer; zinc/zinc alloy/salt solution; iron/zinc/water. It is concluded that the corrosion taking place is due to local currents, and that because of the close proximity of the electrodes of the small local cells secondary products of electrolysis are formed. The factors influencing the course of the corrosion in such a case are the order in which the electrolyte flows over the two metal surfaces, the solubility (as ions) of each metal in the electrolyte, the chemical composition of the electrolyte, and the possibility of deposition of one metal on the surface of the other to form local elements.—O. H. G.

The Reaction Mechanism of the Atmospheric Oxygen Cell in Relation to the Local Cell Theory of Corrosion. G. Brinkmann. (Werkstoff und Korrosion, 1950, vol. 1, June–July, pp. 217–232). A theory for the reaction mechanism of the atmospheric oxygen cell is developed, as follows: The activated charcoal electrode acquires a positive charge through the dissociation of basic groups on the carbon surface, liberating hydroxide ions. Appreciable currents now pass if the carbon is in contact with a metal which is able to give up negative charges by ionizing to positive ions. The basic groups are regenerated in the presence of oxygen and water with the simultaneous formation of hydrogen peroxide. The net reaction is an oxidation of the metal. Experimental confirmation for the combinations charcoal–zinc, charcoal–iron, and charcoal–aluminium is reported, and was obtained by a quantitative study of the oxygen absorbed by multiple cells formed in an intimate mixture of charcoal and metal powder. In the case of charcoal–zinc, if the oxygen-consuming reaction was artificially stimulated by certain electrolytes in the absence of sufficient oxygen, evolution of hydrogen took place. The couple charcoal–aluminium gave anomalous results.—O. H. G.

Evans Cells. K. Wickert and H. Wiehr. (Werkstoffe und Korrosion, 1950, vol. 1, Aug., pp. 299–302). Previous experiments with an Evans cell (nitrogen–oxygen cells with iron electrodes and a sodium chloride electrolyte) have been repeated, this time using cells with a low ohmic resistance. It was again found that unless the electrode surfaces are passivated by fine polishing the metal loss is greater at the cathode than at the anode, the loss at the cathode being the greater the greater the activity of the electrodes. The contrary results of U. R. Evans are attributed to the passive surface of his electrodes.—O. H. G.

The Action of Acid and of Neutral Phosphate Solutions on Mild Steel. II. H. Grubitsch. (Werkstoffe und Korrosion, 1950, vol. 1, Aug., pp. 303–304). Corrosion experiments by the residual current method on mild steel (0·045% C, 0·056% Si, 0·40% Mn, 0·031% S, 0·015% P) in flowing air saturated with (1) distilled water and (2) town's water at 70° C., duration 24 hr., are described. The corrosion measured by the residual current was only a small fraction of the total corrosion. Addition of NaH_2PO_4 reduced the rate of corrosion, minimum corrosion occurring at a *p*H of 4·75. Static 21-day experiments with distilled water and town's water at 15° C. are also described. In both cases addition of NaH_2PO_4 reduced the rate of corrosion. With distilled water a minimum in the corrosion rate against phosphate concentration curve occurred at a concentration corresponding to 4 mg./litre. No pitting occurred in the experiments with town's water.
O. H. G.

The Effect of Diffusional Processes on the Rate of Corrosion. R. C. L. Bosworth. (Journal and Proceedings of the Royal Society of New South Wales, 1949, vol. 83, Part I, pp. 8–16). The variation of the corrosion rate of the surface of a circular disc, protected by a guard-ring, has been studied as a function of the orientation and of the depth of immersion below the surface of the corrosive liquid. The systems studied included copper, copper alloys, and steel in acetic acid and acetic anhydride mixtures. Reciprocals of corrosion rates plotted against depths of immersion gave straight lines, the intercepts of which on the corrosion axis are interpreted as a measure of the corrosion rate under such conditions that the depolarizing agent (atmospheric oxygen) is made freely available at the surface. The slopes of the lines are interpreted as a measure of the ' conductivity ' of the corrosive agent for the depolarizing agent.—P. M. C.

The Influence of Forced Convection on the Process of Corrosion. R. C. L. Bosworth. (Journal and Proceedings of the Royal Society of New South Wales, 1949, vol. 83, Part I, pp. 17–24). The rate of corrosion of metal tubes (copper, copper alloys, steel) through which a corrodant liquid (acetic acid, acetic anhydride mixtures) flows, has been measured as a function of the rate of flow. The variation of corrosion with rate of flow takes the same form as that for the rate of heat loss from a geometrically similar lagged hot pipe through which a conducting fluid is caused to flow. The diffusivity of the depolarizing agent, which is analagous to the thermometric conductivity, is the same for all the metals and corrodants studied, *i.e.*, 5×10^{-3} sq. cm./sec.$^{-1}$ A table shows the properties concerned in the convective loss of heat, together with the corresponding terms involved in the convective transfer of matter in the corrosion process.—P. M. C.

The Influence of Natural Convection on the Process of Corrosion. R. C. L. Bosworth. (Journal and Proceedings of the Royal Society of New South Wales, 1949, vol. 83, Part I, pp. 25–30). The corrosive loss of matter from metal cylinders (copper, copper alloys, steel), immersed horizontally in corrosive liquids (acetic acid, acetic anhydride mixtures), has been measured as a function of cylinder diameter. In most cases the rate of corrosion increases as the diameter decreases. When the dimensionless products of the properties involved in corrosion analagous to the Nusselt, Prandtl, and Grashof numbers are set up, the functional relationship between them is shown to be the same as that applying to the convective loss of heat from geometrically similar bodies.
P. M. C.

The Influence of Pigments on the Corrosion-Preventative Properties of Paints. C. Kalauch. (Werkstoffe und Korrosion, 1950, vol. 1, Oct., pp. 400–404). The action of pigments as corrosion inhibitors in paints is discussed. Electrolytic experiments using films impregnated with ZnO, red lead, iron oxide, $Al(OH)_3$, p-aminophenol, aniline, methyl and dimethyl aniline, and oxygen-water corrosion tests on iron coated with paints containing basic organic and inorganic pigments by the current-time measuring process of Tödt are described.
O. H. G.

The Effect of Amines on the Electrode Potential of Mild Steel in Tap Water and Acid Solutions. N. Hackerman and J. D. Sudbury. (Journal of the Electrochemical Society, 1950, vol. 97, Apr., pp. 109–116). Potentials of mild steel were measured in aqueous N-H_2SO_4 and in tap water, with and without added amines. The steady state potential was found to be a function of the nature and concentration of the amines. The normal potential could not be completely restored when the steel was placed in amine-free solutions if the amine concentration in the original solution was low. Polarization measurements in the presence of amines showed that both anodic and cathodic areas were affected by the inhibitors. Decomposition potential curves for the systems pointed to the same conclusion. The data are discussed in terms of a generalized theory of corrosion inhibition. It is postulated that the measured changes are due to adsorption of the polar compounds on the metal surface. The lack of complete reversibility is attributed to the heterogeneity of the surfaces giving rise to a variety of adsorption energies. Inhibition at anodic areas is considered to be due to a reduction in tendency of iron ions to go into solution as a result of a displacement of electrons from the metal towards the positively charged inhibitor rather than towards the cathodic areas within the metal. The amines may act as inhibitors at the cathodic areas by virtue of diffusion effects, increased resistance, and overvoltage.—J. P.

Corrosion of Austenitic Steels under Tension. W. Tofaute and H. J. Rocha. (Instituto del Hierro y del Acero, 1950, vol. 3, Apr.–June, pp. 101–110). [In Spanish]. The essential difference between intergranular corrosion and stress corrosion is first explained. The technical problems connected with testing are discussed. Time to rupture in relation to nickel and chromium contents is shown. Effects of ferrite and martensite on stress corrosion are examined. Stress corrosion can largely be avoided if the austenite is stable and is associated with quantities of ferrite so as to form local cells to impede corrosion.—R. S.

Corrosion-Erosion of Boiler Feed Pumps and Regulating Valves at Marysville, Second Test Program. J. M. Decker, H. A. Wagner, and J. C. Marsh. (Transactions of the American Society of Mechanical Engineers, 1950, vol. 72, Jan., pp. 19–26). Corrosion-erosion tests at 320 and 385° F. indicated that, at these temperatures, carbon steel is attacked to a lesser extent than at 250° F., whereas the reverse is true of the chromium-bearing steels. However, the rate of attack of the chromium steels is still only a fraction of that of carbon steels so that the use of the alloy steels for feed-pump parts is warranted at the higher temperatures also. Increasing the *p*H of the feedwater from 7·6 to 8·4 doubled the corrosion-erosion attack on carbon steels in the Marysville boiler feed at 250° F. as compared with previous tests at the lower *p*H.
D. H.

Corrosion Testing. T. P. Hoar. (Midland Metallurgical Societies : Journal of the Birmingham Metallurgical Society, 1950, vol. 30, June, pp. 63–72). Three types of test are briefly considered : (1) Testing a series of materials for use in a particular environment ; (2) evaluation of a series of protectives for a particular material in a particular environment ; and (3) a test of environment. The more important methods of assessing corrosion discussed include : (1) Visual observation ; (2) weight change ; (3) chemical analysis of corrosion environment ; (4) change of (*a*) mechanical and (*b*) optical properties, *e.g.*, tarnishing which influences reflectivity ; (5) gas absorption or evolution ; (6) electrode potential measurements ; (7) porosity tests ; and (8) investigation of corrosion mechanism. Special techniques such as the Teddington rotor apparatus and weatherometers are described and examples of tests evolved for special purposes are given.
R. A. R.

" Gas Attack " on Corrosion. (Product Finishing, 1950, vol. 3, Apr., pp. 67–73). The effect of a vapour-phase inhibitor (Shell V.P.I. 260) in preventing corrosion of metal components is described and illustrated. The composition of the inhibitor is not revealed nor is its precise mode of action described.—J. P.

Materials of Construction. (Chemical Engineering, 1950, vol. 11, Nov., pp. 107–154). This report is divided into 13 sections, each dealing with a corrosive chemical, and each having subsections dealing with the suitability of the major types of material used in handling the chemical concerned. The chemicals considered are acetic acid, ammonia, caustic soda, chlorine, fatty acids, hydrochloric acid, hydrofluoric acid, nitric acid, phosphoric acid, sodium chloride, sulphur, sulphuric acid, and sulphur dioxide, and the construction materials include aluminium, carbon, Chlorimets, coatings, Durimets, Duriron, Durichlor, glass lining, iron and steel, lead, nickel and alloys, rubber lining, silicones, stainless steel, stoneware, tantalum, and Worthite. A comprehensive

directory of the manufacturers of these materials and flow sheets for the manufacture of many industrial chemicals with notes on the materials of construction are given. The information is contributed by 43 authors.—J. E. D.

Stop Accelerated Oxidation and Get Better Jet Engines. A. Des Brasunas and N. J. Grant. (Iron Age, 1950, vol. 166, Aug. 17, pp. 85–90). The problems of accelerated corrosion are at present being studied at the Massachusetts Institute of Technology. The alloys known to be susceptible have one or more of the following elements, vanadium, molybdenum, or tungsten ; these elements are unique in that their highest oxides have very low melting points and/or high vapour pressures. Above about 1300° F. alloys are subject to accelerated corrosion, the actual temperature depending on the amount of alloying elements. The desirability of high-nickel alloys to suppress accelerated oxidation is definitely indicated by performance tests.—A. M. F.

The Pathology of Metals. W. J. Copenhagen. (Metal Industry, 1950, vol. 77, Sept. 8, p. 137). After two months in transit, two aircraft in wooden packing cases were badly affected by corrosion and mould growth. The principal fungus was identified as ascomycete, *i.e., ceratostomella spp.* The author concluded that corrosion was due to the use of unseasoned wood containing mould spores, and inadequate ventilation.—P. M. C.

INDUSTRIAL USES AND APPLICATIONS

Steel for Pre-Stressed Concrete. (Aciers Fins et Spéciaux Français, 1950, Nov., pp. 16–18). In 1928 Freyssinet invented a method of prestressing concrete by providing an elastic reserve sufficient to absorb the deferred elastic shrinkage which, under a permanent force of compression after infinite time (2 years in practice), is about twice the initial deformation. The total deformation (initial + deferred) results in a loss in tensile strength of 14 kg./sq. mm. At the present time, drawn wires 2·5 mm. in dia. and 200 kg./sq. mm. tensile strength and 5 mm. in dia. and 150 kg./sq. mm. tensile strength composed of hard steel (0·7% C ; 0·6% Mn ; 0·2% Si) are used for pre-stressing.—E. C. S.

Agricultural Implements : Examples of Weight Saving by Choice of Suitable Steels. (Iron and Steel, 1950, vol. 23, May, pp. 147–150). Examples are given of agricultural implements of Harry Ferguson, Ltd., in which considerable weight saving has been effected by the choice of suitable steels. Details of the steels used for individual implements and for the tractor itself are included.—G. F.

HISTORICAL

Prehistoric Iron : New Finds Indicate Early B.C. Smelting. G. Hopkinson. (Iron and Steel, 1950, vol. 23, May, p. 152). A brief description is given of the discoveries at Norton, Sheffield, indicating prehistoric smelting of iron. The finds include three slag mounds and a smelting pit ; these are of high archæological significance.—G. F.

Pioneers of the Modern Steel Industry. E. N. Simons. (Murex Review, 1950, vol. 1, No. 7, pp. 125–143). A historical review is made of : (1) The development of regenerative heating and the open-hearth furnace by Siemens ; (2) the use of manganese as a deoxidant and production of alloy steels by Mushet ; (3) the prolific inventions of Bessemer including the converter ; (4) the perfection of the Bessemer process by Thomas ; and (5) the work of Sorby on the microscopical examination of iron and steel.—B. G. B.

ECONOMICS AND STATISTICS

The Rôle of Scrap in the Production of Special Steels. (Aciers Fins et Spéciaux Français, 1950, June, pp. 38–39). Before 1939 France was an exporter of scrap but since then export has been strictly controlled by the government and scrap of known origin is allocated to French producers of special steels.—E. C. S.

The Mining and Iron and Steel Industries of Western Europe. F. Hellwig. (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 1004–1014). An economic survey discusses the production and markets for coal and steel of the various countries of Western Europe within the framework of world production. J. P.

The Australian Iron and Steel Industry in Broad Perspective. T. Watson, K. Spencer, A. T. Batty, and W. Dummett. (Institution of Australian Foundrymen : Australasian Engineer, 1950, Aug. 7, pp. 51–58). The article begins with an outline of the history of the Australian industry from 1848. Present annual steel production is about two million long tons, produced by six major firms. High-grade hematite ore, averaging 62–63% Fe, is mined in South Australia, and coal and other raw materials are readily available. The plant, production, and layout of Broken Hill Pty. Co., Ltd., Newcastle, N.S.W., are described in great detail. There are approximately 400 foundries in the country, melting 325,000 tons of metal annually, of which 243,000 tons are grey cast iron. Both iron and steel founding are fully described. In conclusion the country's research facilities, the work of the Universities and Technical Colleges, and the activities of the several trade and professional Institutes and Associations are reviewed.—P. M. C.

MISCELLANEOUS

Industrial Technical Research and Development. Gil Triginer Artigues. (Tecnica Metalurgica, 1950, vol. 6, Mar., pp. 49–60). [In Spanish]. The nature of the organization of research on a national scale is briefly discussed in this paper presented to the Asociacion Técnica Española de Estudios Metalurgicos. A brief outline of the research projects of the Instituto de Investigaciones Técnicas, Barcelona, is given. Work there includes the study of isothermal transformation and the identification of the sigma phase in 25/20 stainless steels.—R. S.

Activities of the Spanish Iron and Steel Institute. (Instituto del Hierro y del Acero, 1950, vol. 3, Apr.–June, pp. 150–152). [In Spanish]. In 1950, the Spanish Iron and Steel Institute organized two important series of lectures : one on acid and heat resisting steels by W. Tofaute, and one by A. Fry consisting of six lectures on ' Fry ' lines, gases in steels, and ageing and precipitation processes in alpha iron. The activities of the Committee and Sections are outlined.—R. S.

Metallurgical Progress and the Steam Engineer. L. Sanderson. (Steam Engineer, 1951, vol. 20, Mar., pp. 203–205) Brief notes are given on : The use of cold driven rivets, surface alloying with chromium, recent work on corrosion of metals, composite iron–steel castings for grate bars, centrifugal casting employing two different alloys, nodular cast iron, and welding of non-ferrous metals.—B. G. B.

Lift Output through Quality Control. C. W. Kennedy. (Steel, 1950, vol. 127, Oct. 9, pp. 86–93). The author describes a number of systems of quality control. It is suggested that a simple but reliable method is to have a sampling point in the production line where the quality level can be determined by the number of defective pieces uncovered in a sample. Advantages gained are impartial assessment of operators' work and an indication of poor machines, tooling, and methods or processes. It is suggested that workers take readily to quality control charts and the cost of control is more than offset by a reduction in rejects. A. M. F.

Sample at Random for Correct Statistical Control. D. Shainin. (Iron Age, 1950, vol. 166, Oct. 12, pp. 172–176). The author stresses the importance of strict random selection of samples for inspection and then discusses the methods of sampling by attributes and variables. The latter method is valuable in that for a specification it gives the average value, the spread of the values, and the shape of the distribution of the values which may be plotted against the frequency of occurrence.—A. M. F.

Occupational Dermatitis in Steelworks. Prophylaxis. F. Mignolet. (Pact, 1950, vol. 4, Dec., pp. 448–450). A description is given of the means available for avoiding the onset of industrial dermatitis from a number of causes, such as oil, acid, and lead-bearing materials. It is found that leather gauntlets frequently aggravate rather than protect the hands from dermatitis and that protective ointments form a better means of combating the diseases.—J. J.

Dust : Public Enemy Number One. Various Processes for Combating It. J. Batlle Gayan. (Acero y Energia, 1950, vol. 7, Sept.–Oct., pp. 14–20). [In Spanish]. The nature of industrial and domestic dusts is discussed. The filter effect is defined as the weight of dust caught, over the volume of air passed through the filter. The author describes cyclones, centrifugal precipitators, cotton filter separators, and electrostatic filters. In the wet class, bubble filters and atomizer-type filters are described.—R. S.

EULER, H. and H. STEVENS. "*Die analytische Arbeitsbewertung als Hilfsmittel zur Bestimmung der Arbeitsschwierigkeit.*" 4to, pp. 93. Düsseldorf, 1950: Verlag Stahleisen m.b.H. (Price DM 9.60)

The application of scientific principles to job evaluation, which enables a proper balance to be achieved between the basic wages of different kinds of workers, is a recent development which has made rapid strides during the last decade. Although there has been a number of publications on the subject during this period, Euler and Steven's book is of particular interest to the iron and steel industry because the practical system it describes was built up to serve the needs of this industry.

The book is divided into two parts, the first of which deals with the principles of job evaluation and the second with the method of putting these into practice.

Part A first sets out to analyse jobs into their various characteristics or the demands they make on the worker, that is to say, the knowledge and skill, responsibility, physical and mental work they require, and the conditions under which the work is carried out. Once the common characteristics of all jobs have been set out the two further steps in job evaluation are first, to weigh each of the characteristics according to its importance in determining basic wages, and secondly, to establish a scale for each characteristic so that the amount of knowledge, skill, etc., needed for each particular job can be expressed quantitatively. The first of these steps is a matter for securing common agreement rather than applying scientific principles; but the attention that the authors have given to the second step is their most important contribution to the science and practice of job evaluation. They describe both a 'ranking' process and a 'points' process for setting up a scale, and, to ensure the most reliable rating they advocate using them in combination with a number of carefully described jobs as examples for comparative purposes. The overall difficulty of any job is finally expressed by an index which is the sum of the points for its separate characteristics. It is shown that the same basic principles can even be used to evaluate the overall difficulty of supervisory or staff jobs. An extensive bibliography of recent publications, mostly German, but including some from other sources, is appended.

Part B describes the various stages in the working out of a job evaluation scheme from the initial listing and description of the various jobs to the final index of job difficulty. To simplify the practical task, there are given for each of the separate characteristics both 'ranking' lists with a percentage scale and tables giving appropriate points for different classes of job. Both the lists and the tables are filled in with examples taken from some 60 jobs, each of which is carefully described in detail in an appendix. It is recommended that both the 'ranking' and the 'points' process should be used, adjustments being made as necessary until both processes rank the jobs in the same order.

It is claimed that the process described has been adopted by the majority of works in the German iron and steel industry and, usually with some modification, by a number of works in other industries.—H. R. MILLS

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AMERICAN IRON AND STEEL INSTITUTE. "*Steel Products Manual.*" Section 21. "*Concrete Reinforcing Bars.*" 8vo, pp. 47. New York, 1951: The Institute.

AMERICAN SOCIETY FOR TESTING MATERIALS. "*ASTM Manual on Quality Control of Materials.*" Prepared by A.S.T.M. Committee E-11 on Quality Control of Materials. Part I—"*Presentation of Data.*" Part 2—"*Presenting ± Limits of Uncertainty of an Observed Average.*" Part 3—"*Control Chart Method of Analysis and Presentation of Data.*" Special Technical Publication 15-C. 8vo, pp. xii + 127. Philadelphia, 1951: The Society. (Price $1.75)

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BRITISH STANDARDS INSTITUTION. B.S. 329: 1951. "*Round Strand Steel Wire Suspension Ropes for Lifts and Hoists.*" 8vo, pp. 27. London: The Institution. (Price 3*s.*)

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